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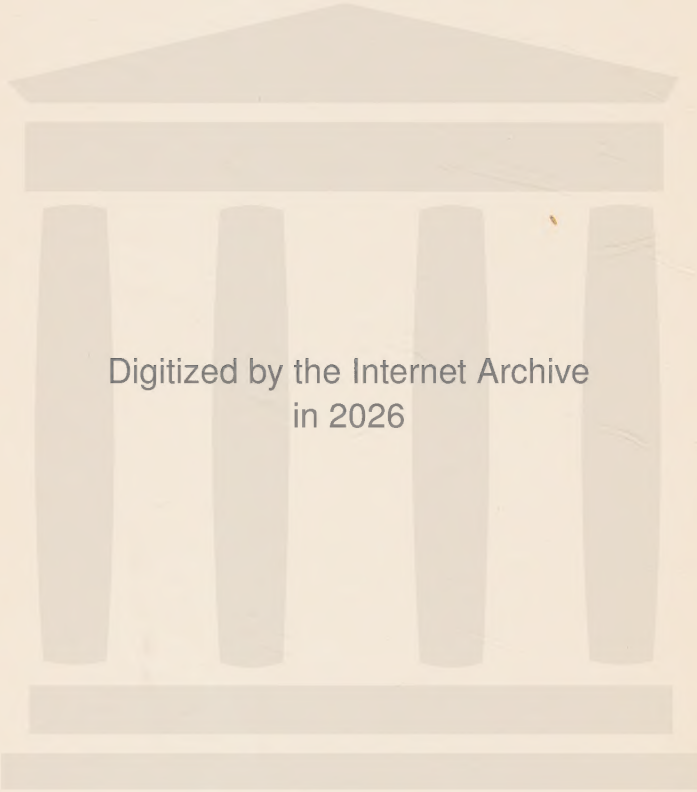


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BACKGROUNDS OF BIOLOGY

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by

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DR. EDWARD J. MENGE
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PREFACE

Although a great number of biological facts, theories, and hypotheses have found their way into the fields of philosophy, education, and sociology, there is still a widespread ignorance of the most fundamental conceptions of this science among students and educated people in general. With our college curricula already overloaded, it would be useless to advocate a standard course of six to eight hours a week in biology for all students. A great number could not find the time to carry such a course in addition to the subjects already required. And yet no student should leave college without being familiar with those fundamental data of biology which play such an important part in the discussion and application of evolution, heredity, health, and kindred topics.

For this reason, the senior author introduced, two years ago, a lecture course in biology at Holy Cross College for all those students who find it impossible to take a standard laboratory course in this subject. One hour a week throughout the entire junior year is being devoted to the course. With the aid of charts, models, and occasional demonstrations, these lectures have created a genuine interest among the students and seem to have supplied a real need. In the present volume, which represents in general the work there done, Chapters I to XI were written by the senior author, Chapters XII to XVI by the junior author, while Chapter XVII has been taken bodily, with the author's permission, from Professor Edward J. Menege's *General and Professional Biology*.

Clearness of expression and simplicity of representation have been the main aims. The authors have tried to keep constantly in mind the fact that the book is principally for students and readers totally unfamiliar with biological topics. Great stress has been laid on bringing to the fore the very fundamentals of biology. It is the lack of a proper understanding of these fundamentals that is at the bottom of the prevailing looseness of

biological thought and writing. We talk, read, and write of the "evolution of man" without knowing what "evolution" implies; we use phrases like "inherited criminal tendencies" without even knowing what "heredity" is; we fight or support, as the case may be, vaccination and other health measures without understanding their biological basis; we brace our pet theories in education and sociology with biological data, the nature and correctness of which we do not know or understand.

To give students and readers who are unfamiliar with biology a background for a proper approach to such problems, is the chief object of this work.

The authors wish to express their appreciation to the following: Professors A. J. MacCormack, S.J., and J. F. Foley, Jr., of Holy Cross College, for reading the greater part of the manuscript; Professors Edward J. Menge and Arthur N. Bragg of Marquette University, for reading the entire manuscript and making many helpful suggestions, and especially to Professor J. F. X. Murphy, S.J., of Holy Cross College, for generously reading the entire manuscript and proofs, and for making many helpful suggestions.

Acknowledgement is due also to Professor E. W. Sinnott and the McGraw-Hill Book Company for permission to use Figure 5 from *Botany Principles and Problems*; to W. B. Saunders Company for permission to reproduce Figures 50 and 51 from McFarland's *Biology, General and Medical*; to Professor H. S. Jennings and the Columbia University Press for permission to use Figures 8 and 10 from *Behavior of the Lower Organisms*; and especially to Professor Richard Goldschmidt of the Kaiser Wilhelm Institut Für Biologie and his publisher, Verlagsbuchhandlung Julius Springer, for their kind permission to use Figures 33, 34, 35, 36, and 37, from *Die Lehre von der Vererbung*. All other illustrations were drawn by Mr. L. D. McGillicuddy and Miss Virginia L. Morrison, to whom the authors wish to express their appreciation and satisfaction.

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BACKGROUNDS OF BIOLOGY

CHAPTER I

THE CELL THEORY—THE CELL AS THE STRUCTURAL UNIT OF LIFE

About the year 1660, the Italian, Marcello Malpighi, personal physician to the Pope, sent a treatise to the British Royal Society in which he made the statement: that the different parts of a plant are made up of small vesicles, which can be observed under the magnifying glass, and which collectively form continuous layers. About the same time an Englishman, Robert Hooke, called attention to the little "boxes" which he had observed while examining a piece of cork with the aid of a very primitive microscope. He called these boxes "cells," and this name has been universally adopted. The findings of these two men were the foundation of Biology's most important generalization; namely, the "cell theory." It took almost two hundred years and the combined investigations of a great number of biologists to formulate this theory in its present meaning. Today the cell theory may be stated thus: *All living organisms are composed of cells, which are the units of structure, function, and development.*

THE CELL, THE STRUCTURAL (MORPHOLOGICAL) UNIT OF ALL ORGANISMS

We may observe the evident fact that a brick house is built by putting together a large number of bricks in a given specified form. These bricks may be of different material, of varied size and shape, and may be arranged in different patterns. But just as these bricks are the structural units of a building, so the cells are the structural units of an organism or any part of an

organism. Let us take, for instance, a single joint of one's own finger. In the innermost center of that joint, there is a small bone. This bone must not be thought of as a homogeneous, structureless mass, somewhat like a piece of iron pipe, but as a structure made up of a great number of similar minute units called "bone cells." Surrounding this bone there is a layer of flesh or muscle, again not a homogeneous mass, but consisting of a great quantity of such units, the "muscle cells." Covering the flesh, there is a layer of skin, made up in similar fashion, of a great number of little units, the "skin cells." The necessity of thinking of all living things in terms of the cell units is best brought out by comparing the finger of a wax model with that of a real finger. The finger of the manikin, like its whole body, is made up of a homogeneous mass of wax, which, when looked at under the magnifying glass, does not reveal any details of structure. The living finger, however, when examined under a powerful magnifying glass, reveals thousands upon thousands of little cells, of varied size and shape, though all of essentially the same fundamental structure. As the finger so the hand, as the hand so the arm, and as the arm so the entire body; each and every part is made up of such little cells, different in size and shape, but all essentially alike.

What is true of your own body, is true of all organisms, from the simplest plant to the most complex animal body. Each is made up of a smaller or larger number of such cells. Not only is every organism, plant or animal, made up of cells, but still more remarkable is the fact that every living being, no matter how complex it may be, comes originally from one such single cell. That single cell is called a "gamete" or "germ cell," and in most cases, is so small that the unaided human eye cannot see it. Considering, therefore, that every organism comes from a single cell and that in its finished form, the adult body, it is really an aggregation of many individual cells, we may understand why the cell is called the "structural unit" of all living things. "It stands to reason, therefore, that a study of the structure, content, origin, and development of the unit cell gives us a bird's-eye view of how living things work and grow. In fact, if one could find *all the possibilities* of any given cell, and then find *why it has these*

possibilities, and just *how* and *why* it develops into the particular structure that it does and no other, the riddle of life would be solved.”¹

What then is a cell? We may answer this question from two different points of view. We may look at the cell from the standpoint of an architect and from the standpoint of a contractor. The former is more interested in the form of a building; the latter is more concerned about the composition of the material out of which the building is to be made. Under the first heading, we shall inquire into the structure and form of the cell; under the second, we shall deal with the substance, the material of which the cell is made.

THE STRUCTURE OF THE CELL

The following comparison may help in constructing a mental picture of a cell². Imagine a child's toy balloon filled with the unboiled white of an egg. In the center of this balloon filled with the raw white of an egg, let us imagine a smaller balloon approximately the size of a tennis ball. This small balloon is also filled with raw white of an egg, and in the latter we imagine a string of beads closely set together and twisted about in an irregular network. Here and there on the string we picture a bead of unusually large size. Thus we have a reasonably good picture of a cell, somewhat as is shown in Figure 1. The rubber of the larger balloon represents the “cell membrane”; the white of an egg within will represent the liquid ground substance or “cytoplasm.” The smaller balloon corresponds to the “nucleus”; i.e., the rubber itself represents the *nuclear wall*; the white of an egg within represents the liquid substance of the nucleus or *nucleoplasm*; the string of beads represents the double network of linin and chromatin; i.e., the string itself stands for the “linin,” the beads on the string for the “chromatin.” The few large beads correspond to the “nucleoli,” one of which is known as the true “nucleolus.”

The cytoplasm (the white of egg within the larger balloon) contains a number of *inclusions* which we shall not consider here. The cell membrane and cytoplasm together form the *cytosome*. The cytosome therefore includes everything outside of the nu-

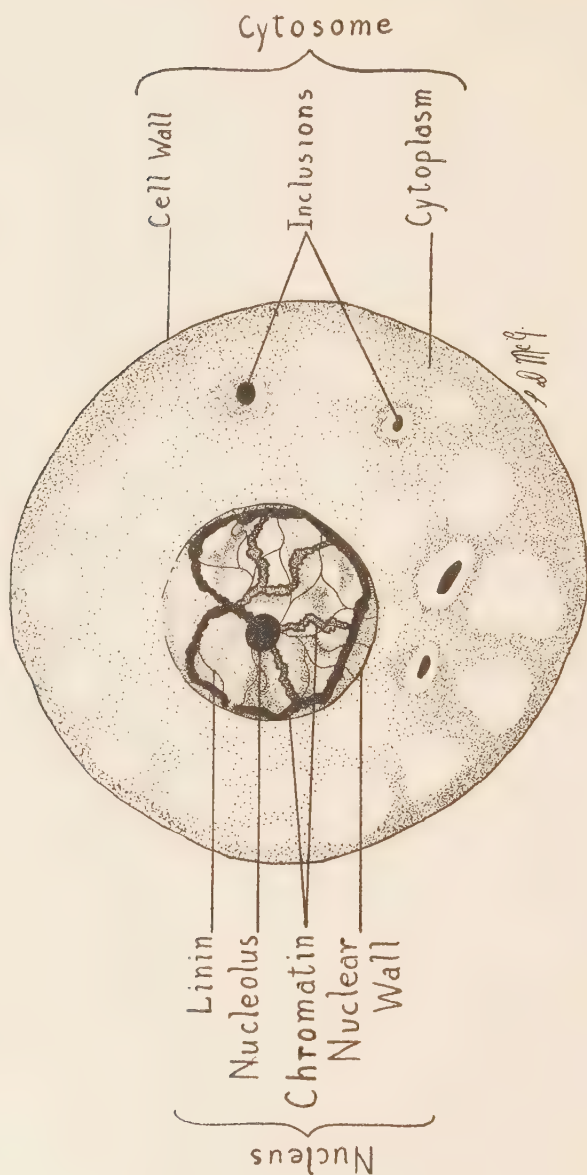
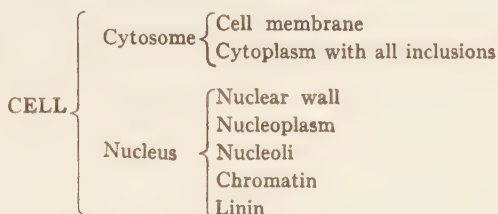


FIG. 1

A generalized cell, based on an egg cell in the ovary of a kitten.

cleus, but within the cell proper. The following scheme may help to keep the structure of a cell in mind.



The structure of the cell, especially of the nucleus, is very effectively brought out when the cell is subjected to the action of different dyes or stains. The various components of a cell react differently toward these stains, a fact which, of course, tends to sharpen the contrast between the different structures of the cell and thereby brings the architecture of the whole cell into stronger relief. This is especially the case with the little central body of the cell, the nucleus. The chromatin—the string of beads in our smaller balloon—has a strong liking for certain dyes; that is, it absorbs these dyes much more than the other parts of the nucleus and cytosome. For this reason, we call this network “chromatin,” which comes from the Greek *chroma*, meaning “color.” The chromatin is, however, not always arranged in exactly the same way in all cells. In many cells, it appears like a dark network, in others as heavy granules distributed throughout the nucleus, while in others again, it may be massed together in one or more little bodies (compare Fig. 2, H). But whatever form the chromatin may assume in a given cell, it is always the most significant substance of the cell. It is essentially the “germ plasm,” the substance which is passed down from generation to generation in reproduction. It forms the “chromosomes” which, at the present stage of our knowledge, are considered the *carriers of heredity*.

DIFFERENT TYPES OF CELLS AND TISSUES

While the original shape of the cell is spherical, most cells are not spherical because of the inequalities of environment and function. As a matter of fact, most cells are adapted to some specialized function and to some peculiar environment. This

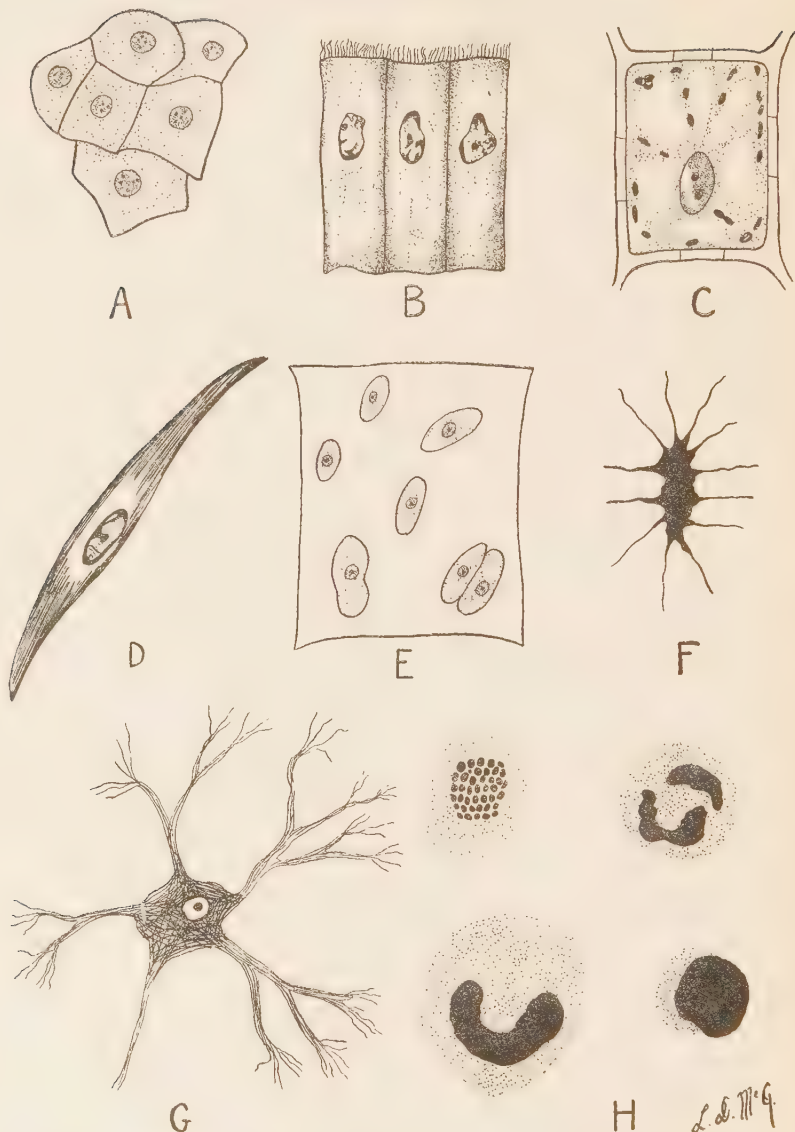


FIG. 2

Different types of cells. A, flat epithelial cells; B, columnar epithelial cells with cilia; C, plant cell; D, smooth muscle cell; E, cartilage cells; F, bone cell; G, nerve cell; H, white blood corpuscle cells.

is best illustrated in the case of "nerve cells." Nerve cells serve as a sort of animated telegraph wires connecting the different parts of the body with each other. For that reason, nerve cells possess a number of processes whose length is determined by the particular location of the cell (see Fig. 2, G). Other cells serve as a covering for surfaces either on the outside of the body; e.g., skin, or on the inside of a cavity; e.g., the linings of the digestive tract, of the heart, and blood vessels. Such cells are more or less flat or blocklike and are called "epithelial" cells (Fig. 2, A and B). Then there are the "muscle" cells, whose function consists chiefly in providing movement. This is accomplished by contraction and expansion. Consequently, muscle cells are inclined to be long and slender, very much like an elastic band (Fig. 2, D).

According to the functional and environmental point of view, we may distinguish in an animal organism the following kinds of cells:

1. EPITHELIAL CELLS—surface lining cells.
2. MUSCLE CELLS—fiberlike cells with great power of contraction and expansion. There are *striated* and *unstriated* (smooth) muscle fibers. The former are also called "voluntary" muscle fibers because they are under the control of the organism; the unstriated are called "involuntary" because they function regardless of the will of the possessor. Muscle fibers of the heart are peculiar in that they are striated, but involuntary.
3. CONNECTIVE and SUPPORTING CELLS—cells specialized to hold together or support different parts of an organism. Examples are bone cells, cartilage cells, and the various types of elastic-fiber cells.
4. NERVE CELLS—cells characterized by long processes or branches which serve to bring impulses to the cell or conduct them away from the nerve cell. These branches are often of great length and are quite numerous.
5. BLOOD and LYMPH CELLS—loose cells floating in the plasma of the blood or lymph. Examples are the red and white blood corpuscles, the marrow cells, and the lymphoid cells. They are all more or less of spherical shape.

6. REPRODUCTIVE CELLS—free, independent cells mostly of spherical or cylindrical shape; e.g., egg cells and sperm cells.

When a number of similar cells adhere to each other in a layer they are said to form a "*tissue*." The purpose of such union is to permit similar function on the part of the connected cells. Thus we speak of "muscular tissue," a number of muscle cells

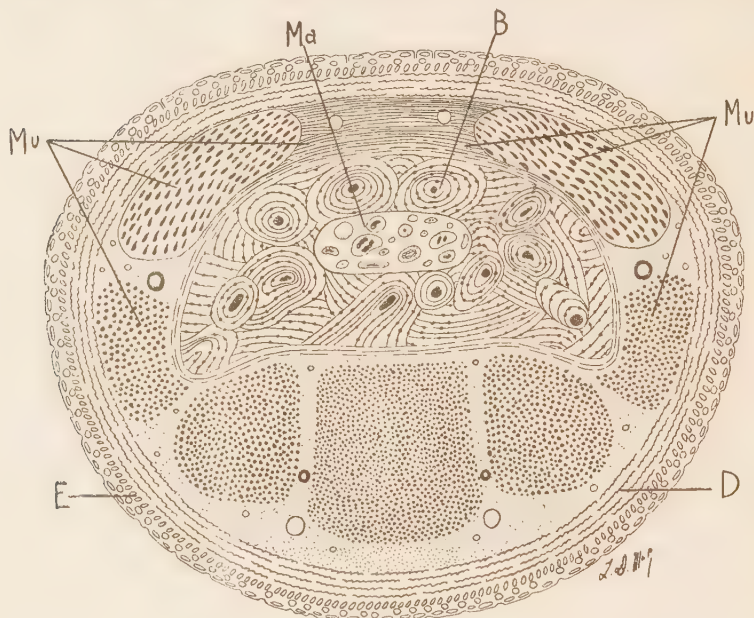


FIG. 3

Diagrammatic cross section through a finger to illustrate various cells composing the tissues. E, epidermis of skin; D, dermis of skin; Mu, muscular tissue; B, bone tissue; Ma, bone marrow.

performing the same type of work. In the same manner, we speak of "epithelial tissue," a number of epithelial cells adhering together to form a surface covering; of "connective tissue," a number of such cells forming a connecting band or supporting structure; and lastly of "nervous tissue," a number of nerve cells or "neurons."

The unison of several tissues to perform a specific function is known as an "organ." Let us for the present revert to our previous example, a joint of one's own finger. The diagrammatic

Figure 3 illustrates the point well. Starting on the outside of the section, you will notice that the skin of the finger consists of two distinct layers or "tissues." There is an outside layer of flat and columnar epithelial cells which, taken together, form the "epidermis" of the skin (Fig. 3, E), and an inner layer of connective-tissue cells, which, taken together, form the "dermis" of the skin (D). Next to this layer, there are bundles of what appear to be a series of dots. These are the cut-off ends of the long, slender muscle cells, and taken together, they form the "muscular tissue" of the finger (Mu). Toward the inside of this muscular tissue you will notice a layer of small, dark cells which lie on the concentric rings of a homogeneous structureless mass. These are the bone cells with their intercellular calcified mass and form the "supporting" or "bony tissue" of the finger (B). The center of the section shows a mass of small and large cells, which are more or less spherical and which together form a modified lymphoid tissue, the "bone marrow" (Ma). Therefore, the finger is made up of several tissues, and each tissue is an aggregation of similar cells of like function. It is now clear why the cell is called the "structural unit of an organism."

THE SUBSTANCE OF THE CELL

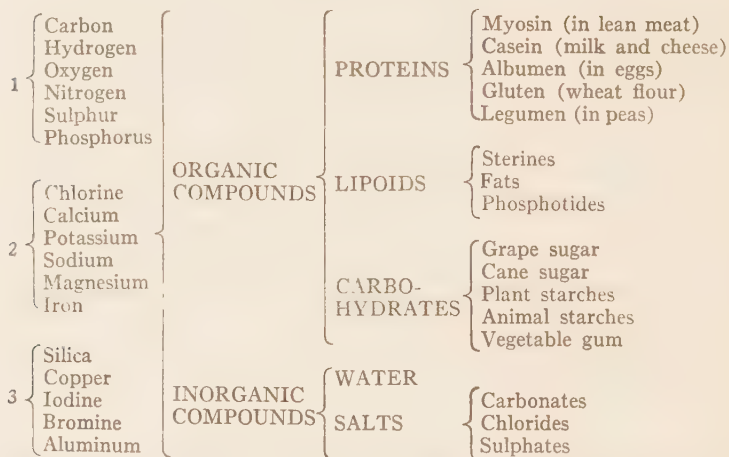
Having a reasonably good conception of the structure of the cell, we may now take the point of view of the contractor and ask what is the nature of the material or substance which makes up this structure which we call the cell. Thus we approach the "chemistry of the cell." We have agreed to call this substance "protoplasm." Let the reader realize from the beginning that this name is not an explanation, any more than any other of the various names given to the material of the cell, such as "nutrient sap," "vital juice," or Huxley's famous "physical basis of life." The word protoplasm means simply "first or original liquid." What then is protoplasm?

THE ORGANIC CHEMIST SPEAKS.—Two methods are used by chemists in their investigations of the chemical composition of new substances. First, the chemist tries to decompose the unknown substance and to determine the composition of the products of its *destruction*. From this he arrives at the chemical

make-up of the unknown substance. This is the "analytical" method. The second mode of procedure (*synthesis*) is the exact opposite of the first; in this method the chemist tries to produce the substance artificially by bringing together its component parts.

Therefore, if the chemist wishes to determine the chemical composition of living protoplasm, he must first of all investigate the chemical composition of the products of its "destruction." Then he must try to form a scheme of the chemical structure of the principal compounds composing protoplasm, and finally he must obtain these principal compounds artificially. The following scheme shows the reader at a glance what the organic chemist has been able to learn about the chemical composition of protoplasm by the analytical method.

PROTOPLASM



CHEMICAL ELEMENTS.—About one fifth of all the known elements enter into the composition of protoplasm. Notice that they are arranged in three groups. The elements in Group 1 occur in the protoplasm of all cells and may therefore be called the essential elements. Those in Group 2 occur in the protoplasm of most cells, while those in Group 3 occur in the protoplasm of only a few special cells. It must be understood that these elements do not occur in protoplasm as "elements" (with the ex-

ception of oxygen), but in definite compounds, both organic and inorganic.

INORGANIC COMPOUNDS.—Water, which is present in great quantity in all protoplasm, is indispensable to life. Later we shall see that protoplasm is a colloid, and that water forms one phase of this colloid.

Some inorganic salts seem to be present in all protoplasm, and we are inclined to think that salts are a necessary admixture to protoplasm. Animals die if fed upon substances entirely devoid of salts. Herbivorous animals hunger for salt, and some of them travel long distances to find the so-called salt licks.

ORGANIC COMPOUNDS. 1. *Carbohydrates*. Carbohydrates are compounds of the elements of carbon, hydrogen, and oxygen. They form the chief source of energy for muscular activity. Plants manufacture their carbohydrates from carbon dioxide and water, whereas animal cells cannot do this and are therefore dependent upon plants for carbohydrates. Well-known examples of carbohydrates are: grape sugar, cane sugar, milk sugar, beet sugar, and malt sugar; also cornstarch, potato starch, and animal starch (the latter stored in the liver of animals). Starches, which are the greatest fuel supply for animals, are stored chiefly in seeds, fleshy roots, and stems. Whence the food value of the various grains and vegetables.

The chemical composition and the structure of carbohydrates are well understood. In fact, chemists have been able to manufacture artificially several carbohydrates; e.g., sugars. Therefore, we may say that the first organic compound of protoplasm is a "chemically known substance," because there is nothing in these compounds that cannot be explained by known chemical laws. However, recent investigations seem to show that carbohydrates are really not "essential" to protoplasm, though they may be in most instances necessary admixtures. The dry protoplasm of red blood cells, for example, consists of about 95 per cent of red proteid (hemoglobin) and 5 per cent lipoids. There is no carbohydrate compound present.

2. *Lipoids*. Lipoids form a large group of organic compounds which are soluble in ether, alcohol, and chloroform. Among them are "fats" found in cottonseed, in linseed, in different kinds of



MARCELLO MALPIGHI (1628-1694)

Pioneer in Cellular Biology

Marcello Malpighi, the oldest son of an Italian farmer, was born in 1628 near the city of Bologna. After obtaining the degree of doctor of medicine from the University of Bologna in 1653, he practiced his profession and lectured at the University for the next three years. His exceptional ability and original method of investigation soon made him many enemies, and we see him wander about Italy for the next ten years. In 1666 he returned to his Alma Mater in Bologna to be her most distinguished professor for twenty-five years. In 1691 Malpighi was called to Rome as the personal physician of the Pope. He died in Rome in 1694.

Malpighi was probably the first man to see "cells" clearly in different organisms. He is considered the founder of microscopic investigation. His researches on the finer structure of the lung, the spleen, the kidney, and the capillaries are of fundamental and lasting importance.

nuts, in butter, lard, and tallow. Specific examples of fat are olein and plamitin in butter. Fats contain the same chemical elements as carbohydrates; namely, carbon, hydrogen, and oxygen, but not in the same proportion. Living protoplasm has the unique power of being able to change fats into carbohydrates and vice versa. To the lipoids belong also the substances called "lipins" which contain, in addition to the three elements of fat, also nitrogen or, sometimes, nitrogen and phosphorus. Lecithin, found in the yolk of eggs, is a specific lipin.

3. *Proteins.* Proteins are very complex compounds of carbon, hydrogen, oxygen, and nitrogen, and probably sulphur and phosphorus. Other elements, like iron and magnesium, are sometimes present. Specific examples are myosin in lean meat or muscle, casein in milk and cheese, albumen in eggs. The resemblance between the words "protoplasm" and "proteins" indicates their close relationship.

Proteins have always been considered the really "essential" compounds of protoplasm, but recent investigations point to the fact that lipoids may also be essential to protoplasm though not in the same sense. At any rate . . . "these protein substances form the chief constituents of many of the fluids of the body, constitute the organic basis of animal tissue, and, at the same time, occupy a decidedly preëminent position among our organic foodstuffs. They are absolutely necessary to the uses of the animal organism for the continuance of life and they cannot be satisfactorily replaced in the diet of such an organism by any other dietary constituent either organic or inorganic. Such an organism may *exist* without protein food for a period of time, the length of the period varying according to the specific organism and the nature of the substitution offered for the protein portion of the diet. Such a period is, however, distinctly one of *existence* rather than one of normal life, and one which is consequently not accompanied by such a full and free exercise of the various functions of the organism as would be possible upon an evenly balanced ration; i.e., one containing the requisite amount of protein food. These protein substances are, furthermore, essential constituents of *all living cells* and therefore without them vegetable life, as well as animal life, is impossible."³

The chemical composition of the proteins is still surrounded by much mystery. In the decomposition of these substances the chemist obtains less complicated compounds, which are known as proteoses, peptones, and peptids, *and which still exhibit true protein characteristics*. On further decomposition these substances, of a protein nature, break down into "amino acids," which, however, do not exhibit any protein characteristics. The chemical structure of these amino acids is known, but how they combine to form proteins is still more or less an unsolved problem. We do, however, know that these amino acids are synthesized within the cells of the organism to form protein material out of which the body builds up its tissue. For this reason, amino acids are often called the "building stones" of the body.

There are only twenty-five known amino acids, but we have ample reason to believe that the number of proteins must be enormous. There seems to be a specific protein for each species of organism, and every organism has different proteins in the different tissues of its body.

RECAPITULATION. Chemical analysis of protoplasm reveals both inorganic and organic compounds. The inorganic compounds—water and various salts—are, of course, perfectly understood and can therefore be synthesized in the chemical laboratory. "Organic" compounds are so called because they occur in nature only as the products of the chemical activities of living organisms. The chemist understands and can synthesize some carbohydrates and fats; that is, he can, in these respects, do in his laboratory what living protoplasm alone can do in nature. His methods, however, are never as simple or direct as the methods of nature.

Quite different is the case of the proteins. No single protein molecule has yet revealed to the chemist its actual structure or its molecular weight, and therefore "synthesis" (artificial manufacture in the laboratory) of proteins is at the present time simply impossible. This, however, does not mean that at some future time it may not be so.

But there is still another very important angle to the question, one too often overlooked by many writers. The organic compounds of protoplasm are the products of its "destruction"; that is, the chemist, by the very nature of his methods, has to destroy

the substance he is investigating. In the present case, this destruction involves the very thing under investigation, namely, *life*. In order to get at the chemical composition of protoplasm the chemist has to kill it—take the *living part* out of it. But it is just that part in which the biologists are interested; i.e., in *living* protoplasm, not in *dead* protoplasm. Consequently, it is not at all certain that the products of its destruction are the same products which are present in living protoplasm. Certainly something must account for the *living* state of protoplasm! Then, too, even if the products were the same after death as before, and if they could be synthesized, there still would be the problem of bringing them together into a structure. This leads to another problem, namely that of the physical structure of living protoplasm.

THE PHYSICAL STRUCTURE OF PROTOPLASM

Much hope as to the solution of the nature of life has lately been based on what is known as the "colloidal theory" of protoplasm, for in our present state of knowledge, protoplasm is held to be a colloid. What then is a colloid?

THE PHYSICAL CHEMIST SPEAKS.—A comparison may help to make clear what a colloid is. Suppose we take a glassful of clear water in which we put a handful of very fine sand. Upon stirring the water, it will be noticed that the grains of sand become for a time suspended in the water, but shortly afterward, they will sink to the bottom; the grains of sand do not stay suspended in the water. Now, if instead of fine sand we take a handful of clay and stir that in water, we see that the water remains turbid. The finer particles of clay do not sink to the bottom, but stay suspended in the liquid. If we put a drop of this clay-water solution under the microscope, we notice the tiny clay particles suspended in the water are all in constant, quivering oscillation (Brownian movement). Water and clay have formed a system—they are in a colloidal state. This particular state is known as a "suspensoid" colloid because solid matter (clay) is suspended in a liquid. Therefore, a colloid consists of two phases: a *dispersion phase* (medium)—in our example, the water; and a *dispersed phase*—in our example, the clay. Whenever a liquid (in-



THEODOR SCHWANN (1810-1882)

Co-Founder of the Cell Theory

"Theodor Schwann was born in 1810 in a small town in Rhenish Prussia, where his father had a bookshop. He studied under his fellow countryman, J. Müller, at both Bonn and Berlin; having taken his doctor's degree, he became his master's assistant. In 1839 he was called to the chair of anatomy at the Roman Catholic University of Louvain, and some years later to Liege, where he worked until shortly before his death in 1882. He was of gentle and reserved disposition; he avoided polemics and therefore accepted none of the professorships that were offered to him at German universities—he did not like the way the German histologists quarreled, he said—and throughout his life he remained a devout Catholic. Thus, he was in everything a contrast to Schleiden, [his co-founder in the cell theory], with whom, nevertheless, he was on friendly terms."

—Erik Nordenskiöld, *The History of Biology*, Alfred A. Knopf, 1928.

stead of a solid) is thus suspended in another liquid we have an "emulsoid" colloid. Protoplasm is such an emulsoid colloid, but of an ultramicroscopic character.

The two phases together are said to form a *system*. Examples of such colloids are milk, which is a water-oil system, and mayonnaise dressing, which is a vinegar-oil system.

It was previously stated that protoplasm is an ultramicroscopic colloid. What does that mean? In the metric system of measurement a millimeter (mm.) is the smallest unit. (An inch is equal to 25 mm.) In biology the smallest unit of measurement, however, is a micron, which is only the thousandth part of a millimeter. With the ordinary microscope we can detect bodies about as small as 0.1 of a micron. Anything smaller than this has to be studied with an instrument called the "ultramicroscope."

However, with the ultramicroscope one does not see the actual bodies, but merely the light reflected from their surfaces, very much as when the pathway of a ray of light passing through a room is made visible by billions of dust particles. You do not actually see the dust particles, but merely the flashes of light reflected from their surfaces. The particles making up the colloidal state of protoplasm are so small that they can be detected only with such an ultramicroscope.

It is only natural that we ask ourselves just what help is this knowledge of the colloidal structure of protoplasm. In order to appreciate the answer we must find out what the essential characteristics of emulsoid colloids are. Let us begin with the most important one called "phase reversal." An illustration may help to clarify the matter. If we dissolve gelatine in water we obtain at first a liquid which, as far as consistency is concerned, is very similar to water. This mixture, called a "sol," is a colloidal system in which particles of liquid gelatine are dispersed through the water. In other words, the water is the *dispersion* medium. If we now stand this mixture in a cool place, the gelatine sets to a mass. Why? Simply because gelatine and water change places; they "reverse." Gelatine now is the dispersion medium in the form of a foamlike reticulum or meshwork, while the water is the dispersed phase in the form of small droplets held in the meshes of the gelatine reticulum. We say then that the "sol"

has changed to a "gel." If we now allow this "gel" to dry and then expose it again to water, we will notice an enormous swelling, for the "gel" imbibes water in great quantity and thereby passes again into the "sol" state. This "phase reversal" and active imbibition of water are the most outstanding properties of emulsoid colloids.

Other characteristics of these colloids are that they will neither crystallize nor osmose, that they absorb foreign particles with great avidity, and that they can easily be precipitated or coagulated by salts and heat.

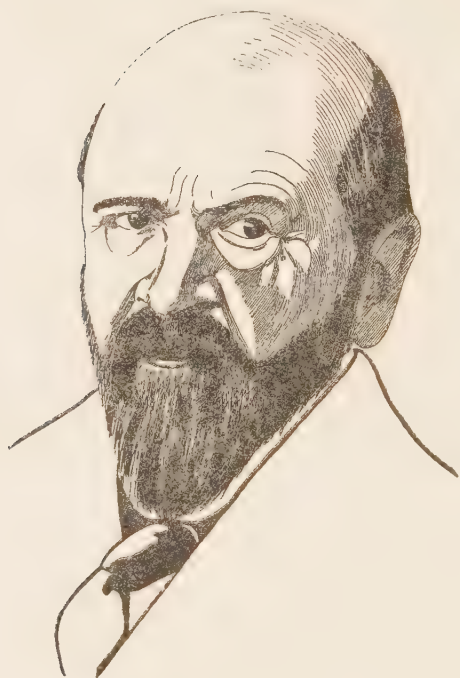
These characteristics of emulsoid colloids help us greatly in understanding many of the physical activities of protoplasm. Let us give an example. You are familiar with the expression "rigor mortis," which consists essentially in a temporary stiffening of the muscles after cessation of the blood circulation shortly after death. The cause of this rigor mortis lies in the increased imbibition of water by the muscle colloids. This increased imbibition is due to the presence of lactic acid which is a post-mortem product. After this lactic acid accumulates in great quantities it causes the muscle proteins to coagulate. This coagulation causes the release of the imbibed water by the colloids of the muscle fibers, and rigor mortis ceases.

Although the colloidal theory explains many of the activities of protoplasm, it does not tell us *why* protoplasm is living. For, it must be remembered that our knowledge of colloids has not come from a study of living colloids, but from a study of dead ones. In other words, all the foregoing characteristics are present in dead colloids as well as living colloids; they therefore cannot be advanced to explain the phenomenon of life in protoplasm. Furthermore, there are "inorganic" colloids, which means that the colloidal state of matter is not restricted to the organic or living world alone.

THE BIOLOGIST SPEAKS.—We may summarize our conclusion in the words of Professor Torrey: "It should be obvious to the student of chemistry that the synthesis of protoplasm in the chemical laboratory is almost a hopeless dream. The more the chemist knows about it, the more he realizes the tremendous chemical difficulties which would have to be overcome in its

successful synthesis. Let it be remembered that protoplasm is the most complicated mixture of chemical compounds known; that its components are fundamentally proteidal and that no single proteid has yet been synthesized. Furthermore, let it be realized that if they could be synthesized, we would not know which ones are essential to the protoplasmic system or how to throw them into the colloidal condition. Last of all they are associated with enzymes and we have little knowledge concerning enzymes. It is only the ignorant man who talks about 'making protoplasm.' Yet we wish to affirm very decidedly that there seems to be nothing metaphysical about protoplasm itself. (We are not speaking here of 'life.') The problem of its synthesis is a chemical and physical problem baffling only because of its terrific complexity."⁴

We have, therefore, to keep in mind the fundamental distinction between *nonliving matter* and *living* protoplasm, not *dead* protoplasm. But, you may ask, what is this fundamental distinction? Without going into details at the present, we may say that it consists in the *organization of the protoplasm into a purposeful unit*. Professor Newman expresses it in the following words: "Life does not inhere in the chemical composition of protoplasm nor in the presence of particular substances nor particular structures, but in the relations of these parts to one another and their integration into a unity of structure and function which we call organization. The cell is, above all, an organism. In an individual composed of one cell, we find that the organism transcends the units of its structure; similarly, in a multicellular individual a deep-seated unity presides over the individual elements that make up its structure . . . "⁵ And Professor Hertwig, famed German biologist, says that: "The work of the investigator of the peculiar problem of life begins where that of the chemist comes to an end," and that "over the growth of the chemical molecules is placed the growth of the cells, and over this again the growth of plants and animals with their unions of millions and milliards of different cells. Chemical knowledge as it exists at present has nothing to do with that new world of organized substances in which the manifestations of life are first made obvious."⁶



HANS DRIESCH (1867-)
Foremost Living Biological Philosopher

Hans Driesch was born in 1867 in Hamburg, where his father belonged to the wealthy merchant class. His financial independence enabled him to give his investigative spirit full reign. Early in his career, he startled the biological world with his original experiments as well as with his outspoken opposition to Darwinism. He soon became the leader of a new and vigorous school in biology. The results of his wide investigations gradually led him to the conviction that the nature of life could not be explained on a causo-mechanistic basis, that, on the contrary, a vital principle or "entelechy" must be assumed.

But what is this organization? Or better, what is responsible for this unity of organization? Is it something physicochemical, something that comes under our known laws of chemistry and physics? Here the parting of the way begins. With this question we are entering into the age-long fight between the mechanistic and vitalistic points of view.

MECHANISTIC AND VITALISTIC THEORIES.—Biologists who hold that the activities of living protoplasm are wholly explainable on a chemicophysical basis are known as "mechanists." To them biology is merely an extension of the sciences of physics and chemistry.

On the other hand, biologists who say that the laws of physics and chemistry are inadequate to explain all phenomena of living protoplasm and hold that there is a vital force, a life principle beyond and above the material forces, are called "vitalists."

Biologists are, on the whole, inclined to suspend judgment in matters of this kind. With very few exceptions all agree that, although no essential difference can be detected in the physicochemical make-up between living and nonliving matter, a complete mechanistic explanation of the activities of living matter is totally impossible at the present time. Most investigators accept the mechanistic theory as a "working hypothesis," that is, they proceed in their investigations of the problem of life on the gratuitous "assumption" that the problem can be solved on a physicochemical basis. In other words, they take it for granted, as in a debate we concede a point (without admitting its correctness) in order that the debate may proceed. This attitude is not only justifiable, but necessary, for otherwise the problem would be removed from the realm of scientific investigation. On the other hand, the "vitalist" insists on a complete explanation, on an adequate cause for every effect, and since the mechanistic explanation is admittedly incomplete and inadequate, since physics and chemistry do not furnish the key to the problem, he leaves their domain and seeks other fields, and enters the realm of philosophy to find an answer to his problem.

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CHAPTER II

THE CELL AS THE FUNCTIONAL UNIT OF LIFE—METABOLISM AND GROWTH BY INTUSSUSCEPTION

So far we have described the cell as the structural unit of all organisms; that is, the study of the cell gives us the form and composition of all organisms. We learned that, with our present knowledge of chemistry and physics, a complete explanation of the living cell is totally out of the question, and that even the most optimistic "mechanist" admits that the activities peculiar to the living cell are far from explained by either the chemistry or the physics of protoplasm. It is time then to ask ourselves, What are these activities so peculiar to the living cell? There is general agreement among most biologists that these activities **can** be reduced to three fundamental functions; namely, (1) metabolism, (2) irritability, and (3) reproduction.

METABOLISM

The German language has a very apt term for the word "metabolism"; namely, "Stoffwechsel," which means literally "change of substance."⁷ Metabolism may be defined as the dual process by which the living cell (1) transforms food into its own living protoplasm, and (2) breaks down its protoplasm for the purpose of releasing energy for the carrying on of the vital processes. The first phase is called "anabolism" or "assimilation," while the second phase is known as "katabolism."

It is important to realize that the essential element of the process of metabolism is not the taking in of foods, or the digestion of foods, or the elimination of the waste materials, but rather the actual transformation of inorganic substances (in the case of plants) and organic substances (in the case of animals) into living protoplasm and energy by the individual cells themselves.

The basis of an understanding of metabolism are certain fundamental physical processes which the student must grasp.

Otherwise this matter will never become clear to him.

Suppose, for instance, that we were outside of a house which has neither windows nor doors. Such a house would be extremely difficult to enter. We have a similar situation in the present case. The food is outside of the individual cells, and the cells are enveloped by a membrane or wall which has neither "doors nor windows" for the entrance of the foodstuffs. But, enter they must! How is such entry accomplished? By the physical processes of diffusion and osmosis.

DIFFUSION

Suppose you have a gas jet in one corner of a room and that, after sealing the windows and the door, you open the jet for a few minutes. At first gas will be found only in the immediate vicinity of the jet. After awhile, you will find gas in the middle of the room, and finally throughout the entire room. If you could take an accurate measurement, you would find that there is just as much gas in the farthest corner of this room as there is in the air immediately surrounding the jet. What has happened? Simply this. The gas, by moving from the point of greater concentration (around the gas jet) to points of lesser concentration, has become evenly distributed throughout the entire space available to it. Another example. Put crystals of salt in a glass of water. You do not even have to stir the water, the salt molecules will of themselves do the same thing that the gas did.

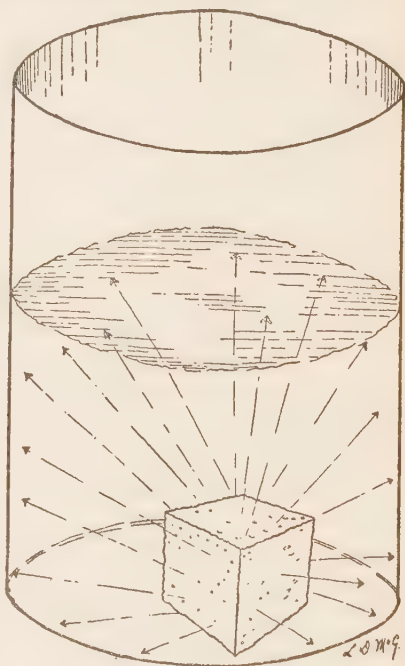


FIG. 4

Diagram illustrating the diffusion of a soluble substance in water.

If you would make an accurate test of the water you would find just as much salt at the surface as at the bottom, and just as much in the center as at the bottom or the top. The molecules of salt have moved from the point of greater concentration to the points of lesser concentration resulting in an even distribution (Fig. 4). You can understand now that by *diffusion* is meant the tendency of any substance, when it occurs as a gas or in solution, to become evenly distributed throughout the entire space available to it by moving from points of greater concentration to points of lesser concentration.⁸

OSMOSIS

Osmosis is nothing but the diffusion of substances in solution through a membrane. If we take the "casing" of a sausage and use it as a bladder, and then fill this bladder with a salt solution and place it in a jar of water, we have an excellent and simple experiment to show how osmosis works. We have two different substances, water and salt, separated from one another by a membrane. Inside of the bladder there is a greater point of concentration for salt, while outside of the bladder are the lesser points of concentration in regard to the salt solution. The salt will now tend to diffuse through the membrane until its concentration is the same on both sides. In other words, diffusion takes place in spite of the membrane. Similarly, the water travels through the membrane toward the inside of the bladder. There is, therefore, a movement of the liquids in both directions at the same time.

The dissolving liquid or "solvent" (water in our example) as well as the "dissolved substance" (salt in our example) pass through the membrane until there is an equal concentration on both sides of the membrane.

All membranes allow water to pass through them, or to put it in another way, all membranes are "permeable" to water. But not all membranes allow other solutions, like salt or sugar, to pass through them. Membranes of this latter type are said to be "semipermeable." A semipermeable membrane allows water to diffuse through it, but it does not necessarily allow a given dissolved substance to do so. The important fact for us to remember is: *All membranes in living cells are semipermeable.*

SELECTIVE OSMOSIS

Now recall what is meant by diffusion, and remember that osmosis is simply diffusion through a membrane. Selective osmosis is diffusion through a semipermeable membrane of selected substances only. It has already been stated that all membranes of living cells are semipermeable; it is necessary to add, however, that this semipermeability is of a "selective nature." The criterion of selection is always the well-being of the living cell. In other words, living cells allow only those solutions which are advantageous to the life of the cell to diffuse through their membranes. This is best illustrated in the root-hair cells of a plant (see Fig. 5). If you examine the smallest rootlets of a plant you will notice that they are covered with minute hairlike projections. Like all parts of a living organism even these hairs are cellular in structure. The root hairs are in intimate contact with the surrounding soil. The soil contains, under proper conditions, water and mineral salts which the plant uses for the manufacture of its protoplasm. Here then, we find a case of being on the outside of the house with neither doors nor windows, and yet having a method of gaining an entrance. How do these nutrient materials pass from the soil into the root-hair cells? By diffusion through the cell membranes, or in other words, by osmosis. The cell membranes allow water and the various salt solutions to diffuse through them so long as there is an unequal concentration of these solutions. But now we must consider an important point. The root-hair cells themselves contain sugar solution which is absolutely essential to the life of the cell and of the whole plant. The surrounding soil, however, does not contain sugar solutions. What does that mean? Simply this, that we have a point of greater concentration (for sugar solution) inside of the cells and a point of lesser concentration in the surrounding soil. According to the principle of osmosis there should, therefore, be a diffusion of sugar solution through the cell membranes into the soil to rob the cells of their most essential substance. Such a process, however, does not take place. The sugar solution is not allowed to pass out through the membrane and the reason is *selective osmosis* (see Fig. 5).

We know of no physical or chemical law which explains this

phenomenon. All we can say at the present time is that the osmotic activity of these cell membranes is regulated by the

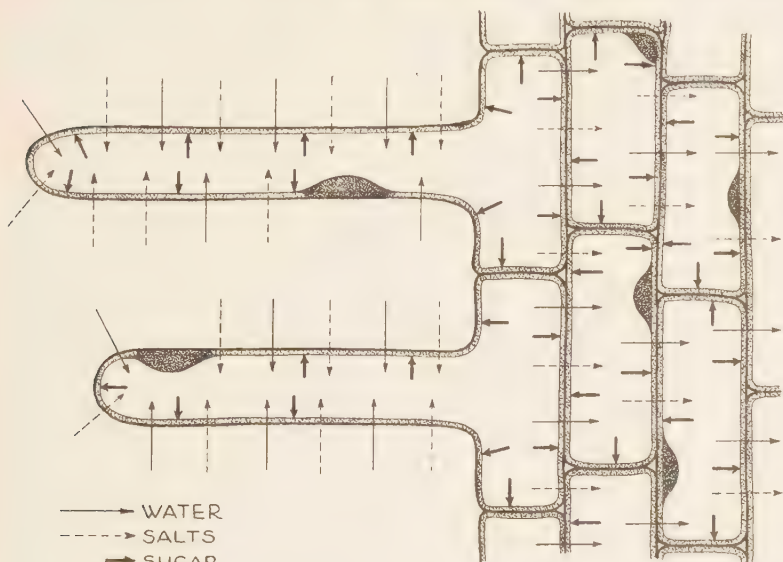


FIG. 5

Movement of water and dissolved substances into the root. Diagram showing the entrance of water and dissolved salts into the root hairs and their passage thence through the cortical cells of the root. The cytoplasmic membranes are readily permeable to water and salts, but prevent the passage of sugar dissolved in the cell sap.

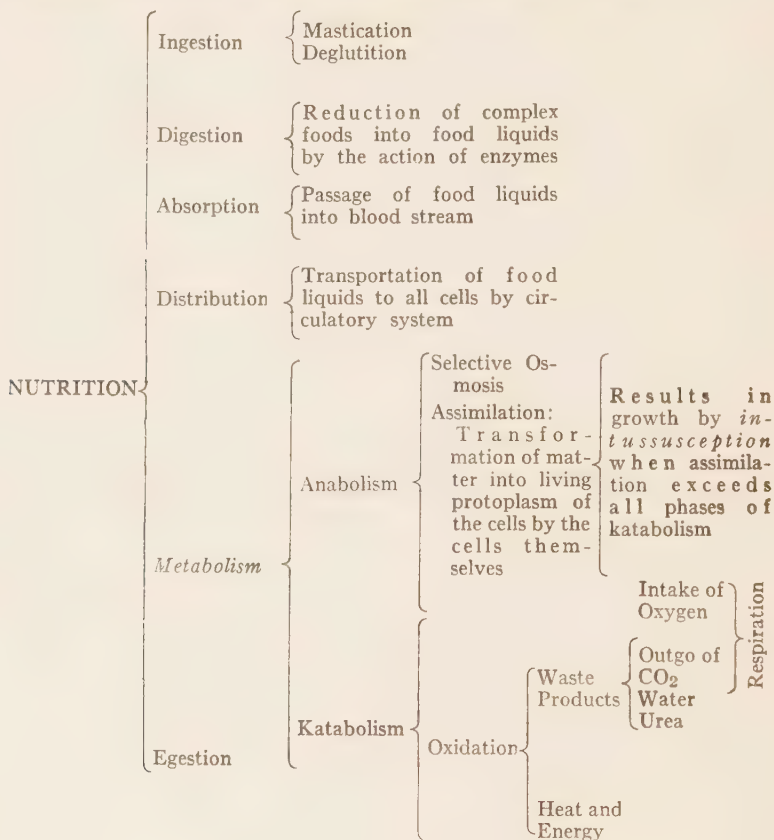
(Redrawn from *Botany Principles and Problems* by E. W. Sinnott.)

well-being of the cells themselves as well as the entire plant of which they are an integral part.

NUTRITION AND METABOLISM

In a complex organism like the human body, the process of metabolism involves many preliminary steps. There are, however, two chief reasons. First, the food material is of a very complex chemical composition and therefore has to be broken down into simpler compounds, while secondly, this breaking down is performed in a restricted part of the body only (digestive tract) making transportation of the food to the other cells of the body necessary. The following diagrammatic scheme gives the reader a bird's-eye view of the steps involved. For the details

we refer the student to a later chapter. At this point, we are interested only in the essential aspects of the problem.



GREEN PLANTS, THE LABORATORY OF PROTOPLASM

In the previous chapter, we learned that protoplasm, in the last analysis, is composed of a number of inorganic substances. How and where are these substances synthesized into the complex organic compounds of the living cell? We know that there are two kinds of plants; namely, (1) the so-called green plants, and (2) those plants which are not green. The difference between the two is due to the presence or absence of a greenish substance called "chlorophyll."

Only green or chlorophyll-bearing plants are able to manufacture protoplasm from inorganic materials. The root-hair cells of green plants are in intimate contact with the surrounding soil, and this soil contains, in addition to water, carbon dioxide, ammonia, compounds of nitrogen, sulphur, iron, chlorine, calcium, and many other mineral salts. By a continuous process of osmosis, these inorganic substances (in a state of solution) enter the root-hairs. From the point of entry the inorganic substances travel to the adjoining cells and so on up to the higher parts of the plant (Fig. 5). Then, too, carbon dioxide from the atmosphere enters the cells. As these different substances pass through the various cells, each cell takes what it needs of the new materials and transforms it into living protoplasm of its own particular kind—*assimilation*. Each cell is therefore chemist and laboratory at the same time. The actual steps involved in this transformation of inorganic substances into living protoplasm are almost completely unknown. Probably sugar is formed first and then starch. The end result, at any rate, is living protoplasm, a complex mixture of proteins, lipoids, and carbohydrates.

Part of this newly manufactured protoplasm is used by the cell in the form of energy; that is to say, the protoplasm burns itself down when combined with oxygen which the plant gets from the air by means of respiration (oxidation). As the burning of the coal is attended by "waste products" in the form of gases and ashes, so the oxidation of protoplasm is accompanied by waste products. The chief waste product in this case in the plant cells is carbon dioxide, which leaves the cell through specially constructed openings in the leaves and stems. Green plants, therefore, do what, at first glance, seems to be a contradictory thing—they take in carbon dioxide and give off carbon dioxide at one and the same time. They take it in so as to enable them to manufacture protoplasm, and they give it off as a waste product of oxidation. Since green plants cannot manufacture protoplasm in the dark, there is no intake of carbon dioxide at night (unless artificial light is used), and as a result the outflow of carbon dioxide is more noticeable.

The other part of the newly manufactured protoplasm is

retained by the cell for its own growth (growth by intussusception) and in the form of stored-up food material.

One of the most noteworthy features of this transformation of inorganic substances into protoplasm is the fact that the compounds of protoplasm contain much more energy than the total amount of energy contained in the original nutrient materials (water, carbon dioxide, and mineral salts). Where does the plant obtain this excess of energy? From the sunlight. The active (kinetic) energy of the vibrations of the light waves is transformed into the latent (potential) energy of the highly complex chemical compounds of protoplasm through the agency of the green substance, chlorophyll. Light waves are therefore the ultimate source of much of the energy in the metabolism of green plants.

Animal cells, as well as the cells of all plants which do not contain chlorophyll (mushrooms and toadstools are examples), cannot manufacture protoplasm from inorganic material. They are, therefore, dependent in part on green plants for their food material. From the green plants they must thus rebuild living protoplasm which, through the addition of oxygen from the air (respiration), is burned down to simple chemical compounds, such as carbon dioxide, water, and urea. These end products (excretions) return to the inorganic world, whence the green plants take them again and transform them anew into protoplasm. Thus the cycle is constantly repeated.

OSMOSIS IN ANIMAL ORGANISMS

Cells of animal organism, like the human body, absorb practically all their food material through osmosis. All food must therefore be brought to a liquid condition, a condition achieved by the process of digestion, which in turn is only a preliminary step to metabolism. (See Chapter XIV on Vertebrate Organization.) The principal food liquids in a higher organism are blood and lymph. They are the medium by which the nutritive material as well as the oxygen is transported and brought into intimate contact with the individual cells of the tissues. The cells which are bathed by these liquids have remarkable power of selection and permit only certain substances to enter. The epithelial cells

of the mammary glands for instance, select from these streams, only such combinations as are best suited to the growing suckling. The careful selection of what is needed by the living cells is well illustrated in the case of certain marine algae. These minute plants are surrounded by sea water which is rich in salts, carbonate of lime, and other substances. Yet these substances are completely neglected by the algae, while they quite readily absorb iodine, a substance present only in almost imperceptible traces.

It is necessary, for the moment, to revert to a discussion of food liquids and animal cells. The student must realize that metabolism is not carried on in these liquids themselves. Blood and lymph are but "the delivery wagon," so to speak, which brings the foodstuffs, in a suitable condition, within the reach of every cell of the body. Each cell takes unto itself by osmosis merely those selected food portions which it happens to need at a given time. After this entry into the cell proper, the simple compounds of the liquid food are transformed or rebuilt by each individual cell into its own particular kind of living protoplasm.

The essential elements of assimilation are (1), in the case of green plants, the manufacture of living protoplasm from inorganic material through the agency of light and chlorophyll; (2) in the case of animal cells, the transformation of organic food material into living protoplasm of their own particular kind.

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CHAPTER III

THE CELL AS THE FUNCTIONAL UNIT OF LIFE (CONTINUED)—IRRITABILITY

Irritability is the power of the living cell to respond to external and internal stimuli by a modification of its structure or function, or of both. In the last analysis, these responses are adaptations to meet the changes of external and internal environment. As such they are intended for the well-being of the cell or the organism of which the particular cell happens to be a structural unit. However, this does not imply that every response must meet with success.

EXPLANATION OF "STIMULUS"

One of the most important points in a discussion of living organism is the fact that an organism cannot exist without an environment. Therefore, when we discuss the two as though they existed separately, it must be borne in mind that in nature no organism exists except in some definite environment, and that the organism's relation to this environment is essential and continuous. By environment is meant both the external and internal vital conditions. Any change in this environment serves as a stimulus, so that stimulus simply means every change in the external and internal vital conditions of the organism. Hence irritability means the ability of the living cell to adjust itself to the changes in the vital conditions.

EXTERNAL STIMULI. By external stimuli are meant every change in the conditions of the surrounding medium on the outside of the cells. By such surrounding medium we mean water, gases, pressure, temperature, light, chemicals, electricity, and other natural forces by which an organism is continuously surrounded. These conditions are in a constant change, and it is this change that the living cell meets. This is best illustrated by referring to atmospheric conditions. Temperature is not constant; on

the contrary, it is forever undergoing changes. It may be cold or cool, warm or hot. The air may be moist or dry; it may or may not be charged with electricity. To all these changing conditions, living protoplasm adjusts itself. In this connection, attention must be called to a factor often forgotten by investigators who study the various forms of irritability by subjecting an organism to artificial or experimental stimuli. They forget there is a natural limit to the power of irritability. "Every organism has certain characteristic ways of acting, which are conditioned largely by its bodily structure, and which limit its action under all sorts of conditions. This seems perhaps a truism. The amoeba [a single-cell animal], of course, cannot swim through water like the *paramoecium* [another single-cell animal], and the latter cannot fly through the air nor walk about land. But the behavior of any given organism is actually confined in this way within narrower limits than is frequently recognized. Formulae [of behavior] have at times been proposed to explain the movements of various organisms, when the latter are incapable of performing the movements called for by the formulae."⁹ Experiments in which strong electrical currents or strong chemicals are used on lower organisms are of more or less doubtful value as to general conclusions. It is questionable whether a proper reaction to such stimuli is really within the power of these organisms.

INTERNAL STIMULI. By *internal stimuli* are meant every change in the internal vital conditions of an organism. These comprise every change in the organs, tissues, cells, cytoplasm, and nucleus; within the cell it includes the arrangement and relations of certain substances, such as proteins, carbohydrates, lipoids, salts, water, and other special components with their interactions and continued alterations.

To recapitulate: by stimulus is meant every change in the vital conditions of living protoplasm.

EXAMPLES OF IRRITABILITY DUE TO EXTERNAL STIMULI

THE SCAVENGERS OF THE BLOOD STREAM. The human blood consists of a fluid in which swim and float millions of minute cells called "red" and "white corpuscles." The function of the red corpuscles is to carry oxygen to all cells of the body. The function of the white corpuscles is to attack and destroy harm-

ful bacteria and dangerous microorganisms which have found their way into the system, and, for this reason, the white corpuscles are often called the "scavengers" of the cellular community. Now the scavenger of the sea is aware of the prey because it senses its presence by sight or smell. The white corpuscles of the blood, however, possess neither vision nor smell nor any other "sense"; therefore, they are unable to "sense" the presence of the harmful bacteria. And yet, they invariably attack the bacteria, engulf, and destroy them. What makes the white cor-



FIG. 6

White blood corpuscle in the process of engulfing bacteria. 1, 2, and 3 denote successive stages.

puscles do this? Here is the answer. Bacteria give off chemical substances, like toxins, which have an *irritating* influence on the white corpuscles; in other words, the activities of the bacteria change the normal environment of the corpuscles. This change acts as a stimulus with the result that the corpuscles move toward the bacteria and, by changing their form, engulf and destroy them (see Fig. 6). Here, then, is the case of a stimulus—the excretions of bacteria and of a response to this stimulus in the form of a movement and temporary change of structure.

Not only do the white blood corpuscles react in this manner, but they respond still further by speeding up their rate of multiplication. In the face of the enemy, they simply increase their birth rate and rush on to the field of battle an ever-increasing army of reserves. This is an additional response to the stimulus started by the bacteria, a response in the form of a temporary modification of a function; namely, reproduction. This double response of the white corpuscles of the blood is essential for the healing of infections and the recovery from infectious

diseases. Health or death in these instances depends largely on whether or not the white corpuscles gain the upper hand over the bacteria. The familiar "blood count" in medical and hospital practice is based on this same phenomenon. If the white corpuscles show an undue numerical increase (if the normal ratio of one white corpuscle to five hundred red corpuscles is disturbed), it is a sure sign of the presence of harmful bacteria, because the undue increase in the number of corpuscles is in response to the activities of the bacteria.

TANNING OF THE SKIN. Another example is the familiar case of "tanning" of the skin. When we expose our skin to the hot rays of the summer sun, the first effect is a "sunburn," a condition which causes the cells of the surface layer of the skin to blister and peel off, exposing the more sensitive tissue. It is important to realize that this "sunburn" is *not* a case of irritability; it is no more a response to a stimulus than the melting of ice by the sun is a response of this sort. The response, in this case, consists in what *follows* the "sunburn." In order to counteract any further "burning" of the skin, certain cells begin to react or respond by manufacturing and depositing a dark pigment which absorbs the rays of the sun and causes the skin to appear "tanned." The stimulus, in this particular case, is the heat waves of the sun; the response consists in a temporary change in the activity of certain cells for their own protection and the protection of the neighboring cells. In other words, certain cells of the skin meet the change in the external vital condition by building up an appropriate defense. If a block of ice exposed to the sun could of its own accord manufacture a substance which would prevent it from melting, here would be a similar case of a response due to an external stimulus. But, of course, everybody knows that ice or any other nonliving substance cannot do such a thing.

OTHER EXAMPLES. Other examples of irritability are some of the common simple reflexes. When a foreign body gets into the glottis we respond by "coughing" to drive it out; when a foreign substance enters the eye a flow of "tears" washes it away; when an irritating substance enters the stomach it is driven out by "vomiting."

EXAMPLE OF IRRITABILITY DUE TO AN INTERNAL STIMULUS

THE PANTING ATHLETE. It has already been mentioned that energy is obtained by the burning down of protoplasm. This burning-down process is dependent on oxygen obtained from the air in the act of respiration, and in this process, a waste product, carbon dioxide, is formed. This waste product has to be removed as fast as it appears. Keeping this in mind, take the case of a runner in a competitive race. He performs his strenuous activity mainly with the muscles of the limbs; that is, the energy is chiefly used by these muscles. When he changes from rest to great activity the need for oxygen on the one hand and for the removal of carbon dioxide on the other are greatly increased.

The initial muscular activity acts as a stimulus to the heart and respiratory apparatus, and they begin to work at a faster pace. The venous blood, filled with carbon dioxide, is pumped back from the limbs in larger quantity by the contracting muscles. Due to the deeper movements of the diaphragm, the heart fills more readily with blood; this brings a greater amount of venous blood into the right auricle of the heart and causes it to beat faster and to discharge a larger amount of blood at a more rapid pace. By this greater output from the heart, the arterial pressure is enormously raised and the blood flow is greatly accelerated. This in turn results in the unfolding of a vast amount of capillaries in the laboring muscles which normally remain closed. All this brings an enormous number of red blood corpuscles (the oxygen carriers) to the muscles of the limbs where they discharge the energy-producing oxygen and absorb the carbon dioxide for transportation to the lungs. The lungs react by deeper breathing, which in turn results in a high percentage of oxygen and a speedier removal of carbon dioxide. Here is a wonderful example of response to internal stimuli: a change in one tissue or organ causes a change in another, and this serves as a stimulus for a change in a third tissue or organ.

OBJECTIVE VS. SUBJECTIVE REACTIONS. The cases here given are illustrations of irritability of a more complex nature. It is important to realize that irritability is a *fundamental* activity of living protoplasm, one which is common to all living protoplasm,

to all plant cells and all animal organisms without exception. When we speak of reactions we are inclined to think of our own "human responses," responses which include such subjective states as choice, desire, memory, intelligence, reasoning, and consciousness. These psychic states cannot be measured by the methods used in an exact science. For this reason, biological workers do not include them in their investigations, but this does not mean that the biologists deny the existence of such responses. Their subjective nature makes it impossible for the biological investigator to apply to them his particular method of procedure: objective observation. By this method he is restricted to such types of reactions as are objective and simple enough to be measured in one form or another. Therefore, it is not surprising to find that practically all studies along these lines have been made on lower organisms where irritability expresses itself in the simplest possible manner. And since *internal* changes are difficult of exact observation even in these lower forms of life, investigative work is almost completely limited to reactions toward *external* stimuli. These simple reactions of the lower organisms are usually spoken of as the "behavior" of these forms.

The biologist exposes these organisms to all sorts of external stimuli. He records, compares, and analyzes their reactions for the purpose of establishing, if possible, general laws which would explain their behavior in a uniform way.

REACTIONS OF THE SIMPLEST ANIMAL

Every beginner in biology is familiar with a microscopic animal called the "amoeba." It is usually spoken of as the simplest animal known, or the lowest form of animal life. It consists of only one cell, but that single cell is capable of performing all essential activities of a living organism. It takes food, which it digests and assimilates, it reproduces its own kind, and finally it responds to changes in the environment. Figure 7 shows one of these amoebae greatly enlarged. The animal is in reality too small for the naked eye; we need a microscope to see it at all. The amoeba looks very much like a tiny drop of unboiled white of an egg, a mere drop of protoplasm. But that bit of protoplasm has a most wonderful architecture. The outer layer of protoplasm

is whitish and quite transparent and free of granules; it is called "ectosarc" or "ectoplasm." Due mainly to great numbers of granules, the inner mass of protoplasm is much darker in appearance; it is called "endosarc" or "endoplasm," and contains two well-defined structures. One is the *nucleus*, a rounded and more solid body. The second is a spherical globule of water, which collapses at more or less regular intervals and empties the water to the outside. This is the *contractile vacuole*.

This little animal reacts to changes in its environment very much as man does. As we draw away from fire, heat, or cold, so the amoeba moves away from the same or similar stimuli. To appreciate this we have to understand how the amoeba, which possesses none of the ordinary organs of locomotion like legs or wings or fins, moves. A good way to explain this little animal's locomotion is to compare the organism with a tractor moving on caterpillar treads. These caterpillars are often lower

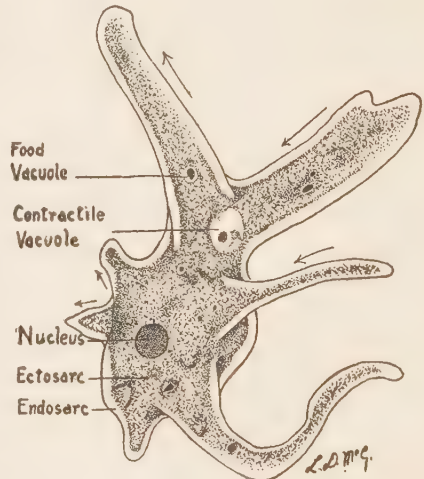


FIG. 7

Amoeba proteus, a single-cell animal.

at the anterior end than at the posterior end. The tractor moves by the caterpillar's turning in such a manner that the top layer moves forward and under; the upper part becomes the lower, while the lower becomes the upper part. In the amoeba the upper surface of protoplasm moves continually forward and rolls under at the anterior end to form the lower surface. Typical of the amoeba in motion is the formation of pseudopodia, that is, "false feet." Various portions of the protoplasm stretch out simultaneously in different directions giving the amoeba the appearance of a hand with outstretched fingers. By looking at Figure 7, one can see that the amoeba can thus move in several directions at one and

the same time. This is of great advantage for orientation and for locating food particles.

It may be useful to observe with Professor Jennings an amoeba in the act of getting food (see Fig. 8). "In the water in which the amoeba lives are found many other minute animals and plants. Upon these the amoeba preys, taking indifferently an animal or vegetable diet. Its behavior while engaged in obtaining food is very remarkable for so simple an animal.

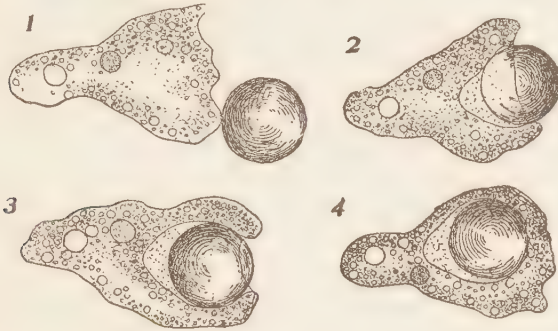


FIG. 8

Amoeba ingesting a *Euglena* cyst. 1, 2, 3, 4, successive stages in the process.
(Taken from *Behavior of the Lower Organisms* by H. S. Jennings.)

"Spherical cysts of *Euglenae* (little organisms which by some are held to be animals and by others to be plants), are a common food of the amoeba proteus. These cysts are smooth and spherical, easily rolling when touched, so that they present considerable difficulties to an amoeba attempting to ingest them. . . .

"A spherical *Euglena* lay in the path of an advancing amoeba proteus. The latter came against the cyst and pushed it ahead a short distance. The cyst did not cling to the protoplasm, but rolled away as soon as it was touched, and this rolling away continued as long as the animal moved forward. Now that part of the amoeba that was immediately behind the cyst stopped moving, so that the cyst was no longer pushed forward. At the same time, a pseudopodium was sent out on each side of the cyst, so that the latter was inclosed in a little bay. Meanwhile a thin sheet of protoplasm passed from the upper surface of the amoeba over the cyst. The two lateral pseudopodia became bent together

at their free ends; the cyst was thus held so that it could not roll away. The pseudopodia and the overlying sheet of protoplasm fused at their free ends, so that the cyst was completely inclosed, together with a quantity of water. It was then carried away by the animal."¹⁰

Thus the amoeba moves, or better, rolls about in a sort of monotonous, uniform way as long as no unusual or disturbing factors enter into the environment. But now suppose some new factors enter into the environment, the equivalent of exposing the little animal to stimuli. Will the amoeba change its course when meeting with an obstacle?

A few examples, taken from Professor Jennings, of Johns Hopkins University, who has done considerable and important work along these lines, will give us an answer:

REACTION TO A CHEMICAL STIMULUS. "If a strong chemical in solution is diffused against one side or end of the body, the amoeba contracts the part affected, releasing it from the substratum, while the protoplasmic currents start in some other direction. The animal has thus changed its course. . . .

"Such experiments show that amoeba is very sensitive to changes in the chemical composition of the water surrounding it, and is inclined to move away whenever it comes to a region in which the water differs even slightly from that to which it is accustomed. It has been shown to react negatively when the following substances come in contact with one side of the body: methylene blue, methyl green, sodium chloride, sodium carbonate, potassium nitrate, potassium hydroxide, acetic acid, hydrochloric acid, cane sugar, distilled water, tap water, and water from other cultures than that in which the amoeba under experimentation lives."¹¹ In these cases the stimulus is a chemical substance, and the reaction or response consists in a movement away from the stimulus. Hence we say that the amoeba is *negatively chemotropic*.

REACTION TO HEAT. "If one side of an amoeba is heated, it reacts in the same negative way as to chemicals or to a mechanical stimulus. The reaction to heat may be observed as follows: An amoeba creeping on the under surface of the coverglass is chosen for the experiment. The point of a needle is heated in a flame

and placed against the coverglass in front of the amoeba, or a little to one side of it. If the needle is not brought too close so as to affect the whole body instead of only one side, the animal responds by contracting the part affected and moving in some other direction."¹² Since the stimulus here is heat, and the response consists again in the form of a movement away from the stimulus, we say that the amoeba is *negatively thermo-tropic*.

REACTIONS OF BACTERIA

Bacteria belong to the smallest and simplest plant organisms. They consist of one cell, though many of them form colonies. For their structure, mode of living, and relations to the other organisms consult Chapter XII on Bacteria. One of the most striking

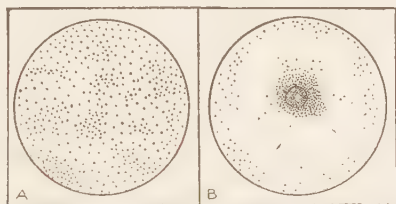


FIG. 9

Diagram showing the reactions of bacteria toward oxygen. A, before adding green algae; B, after adding green algae.

features of many bacteria is their avidity for oxygen. Their reaction to very small quantities of oxygen is so noticeable that it is possible to use them as tests for the presence of small amounts of this gas. The German biologist, Engelmann, found that a bacterium may react to one one-hundred billionth of a milligram of oxygen.

The following example will show how bacteria react to oxygen as a stimulus. Algae (minute plants) produce and give off oxygen as long as they are exposed to light. Put a drop of bacteria culture on a slide and examine it with the microscope under ordinary light conditions. The bacteria are fairly evenly distributed throughout the drop as shown in Figure 9, A. On a second slide put another drop of the same culture, but add to it one of these minute algae. On examining this slide after a few minutes it will

be seen that the bacteria have practically all gathered around this little plant as shown in Figure 9, B. In the foregoing example a change was caused in the external vital conditions of the bacteria by introducing a new factor, the oxygen-producing algae. This added factor is the stimulus to which the bacteria respond by some kind of change. The response is in the form of a movement toward the source of the stimulus which happens to be a chemical. As a result, these bacteria are said to be *positively chemo-tropic*.

Most bacteria do not need light, but there are some bacteria which do need it for their proper activity and development. Engelmann placed some of these bacteria on a glass slide, then illuminated a certain spot from below while he cut off the light from the rest of the slide. Bacteria moving from the darkened area toward the lighted spot entered the latter without any further reaction. Once in this lighted area, however, they remained there. Whenever the bacteria reached the boundaries of the lighted area, they turned about, so that none reentered the darkened area. Now since the reaction is in the form of a movement, it is called a "tropism" or "taxism," and because the stimulus is light the response is said to be a "photo-tropism" or "photo-taxism"; and finally because the bacteria move toward or in the direction of the light they are *positively photo-tropic*. If they were to move away from the light into the dark, they would be *negatively photo-tropic*.

THE TROPISM THEORY

In the foregoing examples the response of the organism consists in a *one-sided movement*; the animal or plant organism moves either toward the stimulus or away from it. The study of such one-sided reactions among lower forms has led to what is known as the tropism theory.

It may be well here to reconsider a few ideas. As already stated, there are two schools in biology, the mechanistic and the vitalistic. The former holds that living phenomena are, in the last analysis, no different from nonliving phenomena; that the same laws of physics and chemistry are sufficient to explain both, though in the case of the latter, the difficulties may be greater. On the other hand, the vitalist claims that all the known laws of

physics and chemistry will not explain the nature of life, that there is something in living protoplasm excelling the forces contained in inorganic matter, and that the nature of life is a problem beyond the realms of physics and chemistry. Now, the "tropism theory" is an attempt to explain in mechanistic terms, i.e., in terms of physics and chemistry, one of the essential or distinguishing characteristics of life; namely, irritability.

First, let us try to understand what is meant by the theory in question. There are two essential points in this theory: first, orientation; second, the production of this orientation by local action.

ORIENTATION. According to this theory, a stimulus *forces* the organism to take a certain position with respect to the source of the stimulus. In this position, the organism is said to be oriented. Ordinarily the organism becomes oriented with its anterior end either toward or away from the source of the stimulus. Once oriented, the organism may move forward in the usual way, and if it does so, it will, of course, move toward or away from the source of stimulation. The essential feature is, therefore, not the forward movement, but rather the process of orientation by which the organism places its axis in the direction of the stimulation so that the anterior end may be directed toward the source of stimulation (positive tropism), or away from the source (negative tropism). It is evident that if a forward motion takes place after such orientation, its direction must correspond to the direction of the stimulus.

PRODUCTION OF ORIENTATION BY LOCAL ACTION. The second feature of this theory is that orientation is produced by direct action of the stimulus on definite localized parts of the cell. When, for instance, a stimulus strikes one side of a ciliated infusorian, the cilia on that side move more or less strongly. This turns the body until the stimulus affects both sides equally, when there is no occasion for further turning; as a result the animal is oriented.

The American biologist, Loeb, says: "These tropisms are identical for animals and plants. The explanation of them depends, first, on the specific irritability of certain elements of the body surface, and, second, upon the relation of symmetry of the body.

Symmetrical elements at the surface of the body have the same irritability; unsymmetrical elements have a different irritability. Those nearer the 'oral' pole possess an irritability greater than that of those nearer the 'aboral' pole. These circumstances force an animal to orient itself toward a source of stimulation in such a way that symmetrical points on the surface of the body are stimulated equally. In this way the animals are led without will of their own either toward the source of stimulus or away from it."¹³

For our present purpose, the important point is that according to this theory orientation is *forced* on the organism by the direct action of the stimulus. The animal or plant organism is, therefore, *passive*. Just as the iron filings are attracted toward the magnet, the organism is led "without will of its own" toward the stimulus or away from it. Given the magnet, the iron filings *must* move toward it; similarly, given the stimulus, the organism *must* move in its direction. As Verworn says: "Thus the phenomena of positive and negative chemotaxis, thermotaxis, phototaxis, and galvanotaxis, which are so highly interesting and important in organic life, follow with mechanical necessity as the simple results of differences in biotonus, which are produced by the actions of stimuli at two different poles of the free-living cell."¹⁴

This theory, one of the first attempts to explain living phenomena on a mechanistic basis, is altogether inadequate to account for even the reactions of the lowest forms of life, much less for the spontaneous movements where there is no perceivable stimulus present. Translated into plain English, the theory states only this: An organism approaches the source of stimulation when moving toward it, and an organism retreats from the source of stimulation when moving away from it. It does not take into account the element of selection which is present in even the simplest movements of the lowest forms of life. The reactions are not *necessitated* by the stimuli. On the contrary, they are *adaptive* and tend to preserve the life of the organism and to help it in performing its normal activities. As a result, the movements in these reactions are not stereotyped, but vary under different conditions and are never the direct result of the physical action of the stimuli. It is impossible to predict the movement of an organism

from a knowledge of the direct physical changes produced in its substance by a given stimulus.

STATUS OF THE TROPISM THEORY. We may summarize the status of the tropism theory in the words of Professor Jennings: "We must then conclude from our examination of the facts that for the lower organisms taken into consideration in the present work, the local-action theory of tropisms is of comparatively little value for interpreting behavior. This theory uses and attempts to make of general application certain elements here and there observable in the behavior of some organisms. But in many organisms, even these elements are almost completely lacking, and in no organism that we have taken up, does this theory adequately express the nature of behavior. The tropism as applied to animal behavior in the sense we have considered, is not an elemental factor; it is only a more or less artificial construction, made by combining certain elements of behavior and omitting others that are of most essential significance. It makes use of certain simple phenomena that actually exist, but elevates these into a general explanation of directed behavior, for which they are utterly inadequate. The prevalence of this local-action theory of tropisms as a general explanation of behavior in lower organisms is based only on an incomplete knowledge and insufficient analysis of the facts of behavior."¹⁵

That there is more than mere "mechanical necessity" in the behavior of the lowest forms is well shown in another experiment of Professor Jennings which may very well close this chapter.

"Amoeba does not always succeed in obtaining its food so easily as in the case described." (See Fig. 8, p. 39.) "Often the cyst rolls away so lightly that the animal fails to grasp and inclose it. In such a case, amoeba may continue its efforts for a long time.

"Thus, in a case observed by the author, an amoeba proteus was moving toward an *Euglena* cyst (Fig. 10). When the anterior edge of the amoeba came in contact with it, the cyst rolled forward a little and slipped to the left. The amoeba followed. When it reached the cyst again, the latter was again pushed forward and to the left. The amoeba continued to follow. This process was continued till the two had traversed about one fourth the cir-

cumference of a circle. Then (at 3) the cyst, when pushed forward, rolled to the left, quite out of contact with the animal. The latter then continued straight forward, with broad anterior edge, in a direction which would have taken it away from the food. But a small pseudopodium on the left side came in contact with the cyst, whereupon the amoeba turned and again followed the rolling ball. At times the animal sent out two pseudopodia, one on each side of the cyst (as at 4) as if trying to inclose the latter, but the spherical cyst rolled so easily that this did not succeed.

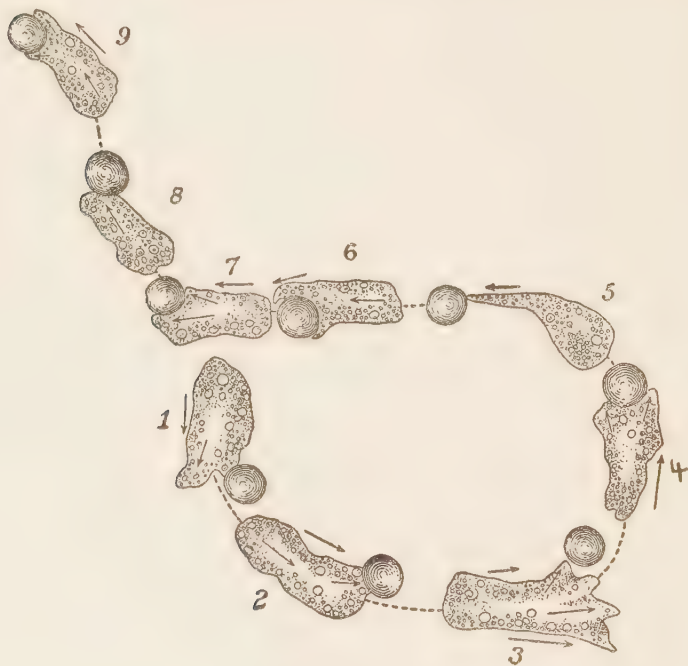


FIG. 10

Amoeba following a rolling *Euglena* cyst. The figures 1 to 9 show successive positions occupied by amoeba and cyst.

(Taken from *Behavior of the Lower Organisms* by H. S. Jennings.)

At other times, a single, long, slender pseudopodium was sent out, only its tip remaining in contact with the cyst (Fig. 10, 5); then the body was brought from the rear, and the food pushed farther. Thus the animal continued until the rolling cyst and the following

amoeba had described almost a complete circle, returning nearly to the point where the amoeba had first come in contact with the cyst. At this point, the cyst rolled to the right as it was pushed forward (7). The amoeba followed (8, 9). This new path was continued for some time. The direction in which the ball was rolling would soon have brought it against an obstacle, so that it seemed probable that the amoeba would finally secure it. But at this point, after the chase had lasted ten or fifteen minutes, a ciliate infusorian whisked the ball away in its ciliary vortex.

"Such behavior makes a striking impression on the observer who sees it for the first time. The amoeba conducts itself in its efforts to obtain food in much the same way as animals far higher in the scale."¹⁶

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CHAPTER IV

THE CELL AS THE UNIT OF GROWTH AND DEVELOPMENT—CELL DIVISION

We come now to what may be rightly considered the cardinal point in the cell theory; namely, the cell as the unit of origin, development, and growth of all life. An organism can grow in size only through an increase in the number of its cells. The adult is bigger than the child solely because of the greater number of cells constituting his body, and the only way in which the child reaches the adult stage is through a steady increase in the number of its body cells. Furthermore, every plant and animal organism, no matter how complex or massive it may be in its finished adult form, begins life as a single cell. This is true of the lowly worm in the soil as well as of the giant elephant in the jungle; it is true of the simple blade of grass on the lawn as well as of the most beautiful flower in the conservatory; finally it is true of the human body. In short, the cell is the unit of development and growth. The first to express this idea clearly and concisely was the German physician, biologist, and statesman, Rudolph Virchow, the scientist who formulated the modern conception of disease and laid the foundation for the all-important study of pathology. His famous dictum, "*Omnis cellula ex cellula*" (every cell from a previous cell), is today universally recognized as the most important law of the cell theory.

How, then, do cells increase in number, and how do they come from a single germ cell? There is only one method by which a new cell can originate: *by a division of a cell already existing*. Today we know, beyond doubt, that new cells arise only from parent cells by division of the parent cells. Upon this process of cell division depends not only the growth of an organism, but the very continuity of life itself. If cells should cease dividing, life would soon disappear from the earth.

There are two types of cell division. One is quite simple and direct; the other is very complicated and presents many stages. The first is called "amitosis" or "direct cell division"; the second is termed "mitosis" or "indirect cell division." Amitosis is restricted almost entirely to the lowest forms of life and has only a passing interest. Mitosis or indirect cell division is the universal method among higher organisms and holds the key to a proper understanding of their development and growth.

MITOSIS OR INDIRECT CELL DIVISION

First recall to mind the structure of the cell as given in Chapter I. It is typically a spherical ball of protoplasm which contains in the center a smaller ball of protoplasm called the "nucleus." Since the nucleus takes the most important rôle in this division, it is necessary to understand thoroughly its structure. It consists of a nuclear wall inclosing a more or less liquid substance, termed "nucleoplasm" or "karyoplasm." Through this nucleoplasm runs a double network, a fine thin network called "linin," and a coarser, darker network, termed "chromatin" (see Figs. 1 and 2). The chromatin takes the leading rôle in this performance, in fact the whole elaborate process seems to take place for the benefit of this chromatin material.

Various progressive stages of mitosis are somewhat diagrammatically represented in Figures 11 to 17 inclusive. By referring constantly to these accompanying figures it will be easy to understand the process.

The first sign of an approaching cell division is a running together of the chromatin network into denser masses; otherwise the nucleus is still unchanged. Simultaneously there appears close to the nuclear wall, but in the cytoplasm, a minute body called the "centrosome." It consists of three parts: a very small central body, the "centriole"; a dark area, the "attraction sphere"; a halo of radiating fibers, the "astral rays." (Fig. 11.)

The chromatin masses now form a long continuous thread or coil, the "spireme." The single centrosome has divided into two centrosomes, which have moved apart a little. The astral rays of the centrosomes are more pronounced. The nuclear wall is breaking up, probably due to the action of the rays. The whole nucleus



FIG. 11

Cell showing first signs of approaching division.



FIG. 12

A slightly later stage, called the "spireme phase."

is losing its typical structure; the linin network and the nucleoli have disappeared into the general protoplasm of the cell. (Fig. 12.)

Figure 13 shows a somewhat later stage. The centrosomes have traveled farther apart from each other. From each centrosome a cone-shaped set of fibrils radiates toward the opposite centrosome. These newly appearing fibrils are called the "spindle fibers"; the figure they form is termed the "spindle." The most significant change, however, has taken place in the chromatin substance. The spireme of the previous phase has broken up into a definite



FIG. 13

Appearance of spindle fibers and formation of chromosomes.

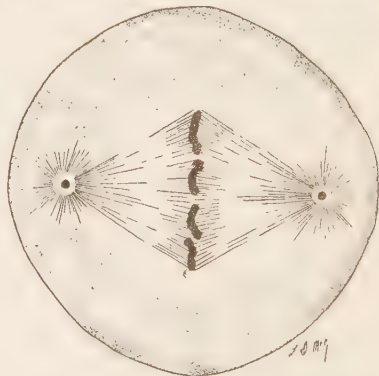


FIG. 14

Chromosomes resting on the equator of the cell.

number—four in our case—of long, twisted rods, called “chromosomes” (do not confuse chromosomes with centrosomes). The nuclear wall has completely disappeared.

In Figure 14 the chromosomes have moved to the equatorial plane lying exactly midway between the two centrosomes. The spindle fibers are fully developed, forming a conspicuous figure not unlike two ice-cream cones facing each other with their open ends. The chromosomes are apparently held in their balanced position in the center by some of the spindle fibers.

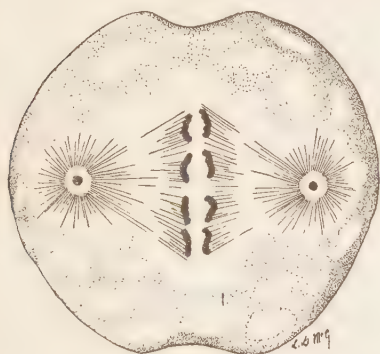


FIG. 15

Division of the chromosomes in two equal halves.

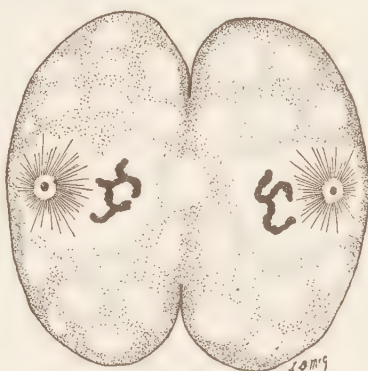


FIG. 16

Chromosomes located at opposite poles; appearance of division plate.

The most significant step in the process has taken place. Each chromosome has been pulled apart along its longitudinal axis into two equal parts. Where formerly there were four chromosomes there are now eight. It is to be noted that each of the two opposing chromosomes are exactly alike, one being a mirror image of the other. This exact equivalence of the two daughter chromosomes is of great importance for the process of normal growth and heredity. The actual pulling apart of the chromosomes seems to be done by some of the spindle fibers. At this time, the first change in the cell proper appears in the form of a slight constriction at each side. (Fig. 15.)

In Figure 16 the chromosomes have traveled farther away from the equator of the cell; each set of four chromosomes has moved along the spindle fibers to its nearest centrosome. The chromo-

somes are just beginning to lose their characteristic form and identity. The constriction at each side of the cell body is more pronounced, and a plate has started to grow across the cell body from one constriction to the other.



FIG. 17

Final stage in the division of a cell.

In Figure 17 is shown the process of division in its final stage. The chromosomes have completely lost their individuality; the chromatin material is scattered again in the form of granules along the threads of the linin network which has meanwhile reappeared. Two nuclear walls have been formed and the nucleolus makes its appearance. The spindle fibers are almost completely obliterated and the centrosomes now lie closely against the nuclear walls. The original single cell is divided into nearly equal parts by the constriction and the finished cell plate. There are two daughter cells in place of the original parent cell and, except for size, each daughter cell is a replica of the parent cell. Ordinarily there now follows a period of rest from cell division. During this period the daughter cells grow until they reach the maximum size. Each daughter cell will then go through exactly the same process, thereby increasing the number of cells to four; these four will do the same thing, bringing the number of cells to eight. Thus the cells increase as long as the normal development and growth require it.

SIGNIFICANT FACTS ABOUT MITOSIS

From the preceding account, it is apparent that the whole complicated process in indirect cell division takes place for the benefit

of the chromatin material. The purpose is to effect an exactly equal distribution of this substance from the parent cell to the resulting daughter cells. The method by which this is accomplished is the formation of chromosomes; namely, the arrangement of the chromatin material into a definite number of rods or segments. *The number of these chromosomes is constant for all cells in a given species.* For example, in all cells of the frog this number is 20; in the cells of the grasshopper it is 24; in the cells of the onion 16; in the cells of the human body probably 48. In some species the number is as small as 2, in others as large as 200.

Many widely different species have of necessity the same number of chromosomes. Thus 16 chromosomes are found in the cells of the onion, wheat, snail, and many other animals and plants. From this it is apparent that the number as such is not the essential feature in cell division; it is the make-up or constitution of the individual chromosomes. The arrangement into a certain number is only a means to attain a uniform transmission of the chromatin particles from the parent cell to the two daughter cells. The important point is, therefore, the structure or composition of the chromosomes. Though our knowledge in this respect is still very limited, we have learned enough to form a fair idea of the matter. Under ordinary magnification, a chromosome appears as a homogeneous mass; in reality, however, it is composed of a greater or smaller number of minute units known as "chromomeres." A chromosome may, therefore, be compared to a string of pearls, each pearl on the string representing a chromomere. Since we have conclusive evidence that the chromomeres determine the characters or traits of the individual, it is apparent that the splitting of the chromosomes during indirect cell division has for its purpose an equal division and distribution of chromomeres. In other words, the important point is not *how many strings* of pearls you own, but *what kind of pearls* make up the strings. The full significance of this matter will become clear in the discussion of heredity.

DIRECT CELL DIVISION OR AMITOSIS

In the lowest forms of life, and rarely in some cells of higher forms, the method of cell division is quite simple and direct.

The nucleus, usually a spherical body, first elongates, then assumes a dumb-bell shape, and finally splits into approximately two equal parts. A constriction or plate divides the cell body, and where formerly there was one cell there are now two (see Fig. 18). These grow until the normal size is reached and the same simple process of division starts again. This extremely simple type of division enables the single-cell animals and plants to multiply at an enormous rate of speed. A single bacterium, after gaining entrance into the system, may, under favorable



FIG. 18

Fission of *Amoeba proteus*, an example of direct cell division. 1, 2, and 3 denote successive stages in the process.

conditions, multiply into billions during the short span of twenty-four hours. In this light, it is not surprising that some of the germinal diseases reach the danger point with such alarming swiftness.

REGENERATION

One of the most remarkable properties of living cells is their ability to replace lost parts. When we lose a portion of skin it is soon replaced. How is this accomplished? Simply by the cells of the surrounding area dividing, multiplying, and growing over the injured part. The scar which usually marks the spot of the injury is a monument to the zeal of the cells. In their anxiety to heal the wound the cells work, as it were, overtime. Cell division in such instances takes place at a faster rate of speed to meet the existing emergency. The injury acts as a stimulus

to the neighboring cells which react or respond by a faster rate of multiplication than is the case under normal conditions. Regeneration is seen to be really a special form of irritability, a response to a stimulus.

The power of regeneration is greatest in the lowest organisms where specialization is less pronounced. There is a little animal, called the fresh-water *Hydra*, which is used quite extensively in biology classes as an example to illustrate regeneration. A *Hydra*



FIG. 19

A fresh-water *Hydra* with five tentacles.



FIG. 20

A fresh-water *Planaria*. d, branches of digestive tract; e, eye; ph, pharynx.

(Fig. 19) may be compared to a "cat-o'-nine-tails," the handle representing the body of the animal and the lashes or thongs representing the tentacles of the *Hydra*. This little creature, barely an inch long when fully expanded, may be cut into as many as thirty pieces, and each piece will form a whole animal, body and tentacles. A similar capacity for regeneration is found among many worms. The little flat worm *Planaria* is another classical example. Though this worm is well differentiated into

anterior and posterior regions (Fig. 20), it may be cut into several small pieces, and each piece will be seen to regenerate all parts which were lost through the cutting.

As the scale of life is ascended, this power of regeneration decreases more and more. Lobsters, crayfish, and some salamanders and lizards still possess the ability to replace lost limbs, but that is the very limit of their regenerative capacity. Among the higher vertebrates, regeneration is reduced to a minimum. While we may regrow a small piece of skin we cannot replace even the smallest joint of a finger or toe. The more a cell is differentiated for a particular function the smaller is its capacity for regeneration.

TUMORS AND CANCEROUS GROWTHS

One of the most dreadful ills the human flesh appears to be heir to is the various forms of neoplastic growths. If they are benign or mild they are termed "tumors"; if malignant and fatal they are commonly called "cancers." Tumors grow by expansion, and slowly push the tissue away, but they do not grow into the tissues. Usually they remain single and localized, and cause no harm except by reason of their position. On the other hand, cancers grow fast and actually invade the tissues, thereby separating and disarranging the cells and causing malnutrition. Cancerous cells have a tendency to invade the blood stream, and for this reason they recur even after the most drastic surgical removal.

But what have tumors and cancers to do with our present topic? Everything in the world! For tumors and cancers are nothing but cells in a riot of division! What causes cells to start such uncontrolled division we do not know. The scientist who discovers that cause will be the greatest benefactor of mankind since the days of the immortal Louis Pasteur.

CHAPTER V

THE CELL AS THE UNIT OF GROWTH AND DEVELOPMENT (Continued)—REPRODUCTION

Reproduction is the ability of living beings to produce and propagate their own kind. There are many modes and ways by which the different groups of organisms accomplish this process. Some are extremely simple; others are very complicated. But the result is always the same: the reproduction of an individual essentially the same as the parent organism. For our purpose "gametic" or "sexual" reproduction is of greatest interest and instruction, because it is the only method of the higher forms of life. However, before explaining the various phases and stages through which the germ cells or "gametes" of higher forms pass, it may be interesting, as well as instructive, to give a brief account of some of the modes of reproduction common among the lower forms of life.

SIMPLE FORMS OF REPRODUCTION

BINARY FISSION. Among single-cell plants and animals, reproduction takes place by direct division of the single-cell organism into two independent cells (see Fig. 18). The cell body elongates and develops a constriction, sometimes at right angles to its longitudinal axis, sometimes at right angles to its transverse axis. Meanwhile the nucleus undergoes a similar elongation during which it assumes a more or less dumb-bell shape. The nucleus then divides into almost two equal parts; the cell body breaks through at the constriction, and where formerly there was only one organism, there exist now two separate, independent individuals. These two cells are like the original except that they are smaller. However, they soon grow to the size of the original parent cell and then undergo the same direct division. This simple method of asexual reproduction is called "binary fission."

SPORULATION. Many single-cell animals multiply by means of what may be called a "short cut." In such cases the nucleus undergoes repeated divisions inside of the original cell body so that the single cell or cytosome contains a dozen or more nuclei. The cell body then breaks into a number of minute protoplasmic masses, each of which contains a nucleus. Each nucleated mass

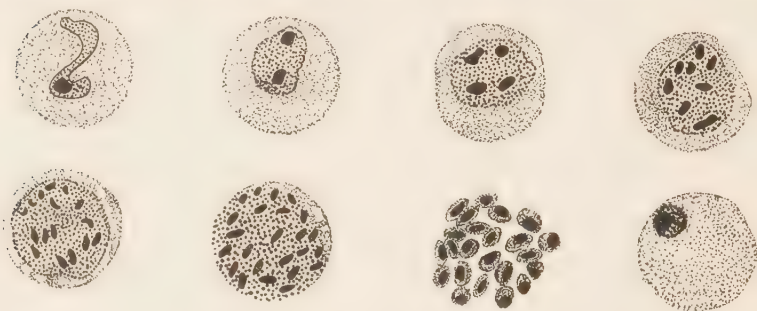


FIG. 21

Successive stages in the sporulation of Malaria germ *Plasmodium vivax*. The germ, a single-cell animal, enters a blood corpuscle, grows in size until it fills the corpuscle completely. The nucleus undergoes repeated divisions until there are as many as 24 inside of the original cell. The blood corpuscle breaks up liberating the nuclei, each of which is surrounded by a thin layer of cytoplasm. A new invasion of corpuscles then takes place.

grows into a full-size individual which in turn repeats within a short time the same process. By this method of reproduction, organisms are able to multiply at a very fast rate. An example of this mode of reproduction is found in the malaria germ, *Plasmodium vivax* (see Fig. 21).

BUDDING. One of the most interesting forms of reproduction occurs in the little fresh-water *Hydra*, an animal which we have already mentioned in our discussion of regeneration (Fig. 19). It will be remembered that the *Hydra* consists of a cylindrical, hollow body, the anterior end of which possesses a row of long projections called "tentacles." The first sign of an approaching reproduction in the *Hydra* is marked by a small wartlike swelling which grows at right angles from the side of the body (see Fig. 22). This swelling keeps growing in length until it forms a hollow tube like the body of the *Hydra* from which it grows. Next, small tentacles start growing out of the

free end, and before long the bud breaks off from the parent body and becomes an independent individual. It is not uncommon to find several such buds in different stages of development on the same *Hydra* (Fig. 22). This type of asexual reproduction is known as "budding."



FIG. 22

A fresh-water *Hydra* with two buds.



FIG. 23

A fresh-water *Hydra* with ovary (*o*) and testis (*t*).

GAMETIC REPRODUCTION IN LOWER FORMS

The three types of reproduction described in the preceding paragraphs are asexual, that is, no specialized germ cells are involved. Among the lowest forms of life asexual reproduction is the ordinary method of multiplication, but at times even these organisms are apparently forced to employ gametic reproduction. For instance, during the greater part of the year the fresh-water *Hydra* multiplies by the asexual method of budding, but during the late fall it ceases to form buds and develops true sex cells: sperms and eggs. One of the interesting features in this connection is the fact, that the same individual *Hydra* produces

both kinds of germ cells at the same time. In other words, the *Hydra* is, during this period of sexual reproduction, a true "hermaphrodite": it possesses simultaneously functional germ cells of both sexes. The male germ cells or sperms arise from a swelling near the anterior end of the body, while the female germ cells or eggs are formed in a similar swelling nearer the posterior or basal end (see Fig. 23). At first there are a great many eggs in the "ovary," as this swelling is called, but only a single egg becomes functional. The others are sacrificed to enrich the yolk content of the one cell which is destined to begin a new generation.

When the sperms are mature the swelling or "testis" containing them ruptures and thereby releases the sperms into the water. About the same time the wall of the ovary breaks and exposes the single egg cell, which remains attached to the parent body. The exposed egg attracts the sperms which happen to be in the neighborhood. Only one sperm, however, penetrates into the egg to fertilize it. After this union, the egg, still attached to the parent body, undergoes development until it forms a small double-walled sac called the "gastrula." In this state, the young embryo separates from the mother *Hydra* and drops down to the bottom of the water where it passes the winter months in a dormant state. Before separating from the parent body, the embryo protects itself against possible enemies and unfavorable conditions by secreting around its tender, unfinished body a hard capsule. With the advent of spring, when environmental conditions become more favorable, the capsule about the embryo ruptures, and the embryo is free to complete its development. After reaching the adult size the new *Hydra*, in its turn, reproduces for a time by the asexual method of budding, but eventually the time comes when it, too, has to form egg and sperm cells.

SINGLE-CELL ANIMALS AND GAMETIC REPRODUCTION. Still more remarkable is the fact that even the single-cell animals change at intervals from ordinary binary fission to gametic reproduction. It may seem impossible that a single cell should develop gametes, but nature is full of apparent impossibilities. For illustration,

let us choose the *Paramecium*, a single-cell animal known to every beginner in the study of biology.

The *Paramecium* in shape may be compared to a cigar which has a broad pointed posterior end and a narrow blunt anterior end (see Fig. 24). Like the amoeba, it consists of a coarse, granulated inner mass of protoplasm called "endosarc," and a transparent, finer outer layer of protoplasm called "ectosarc."

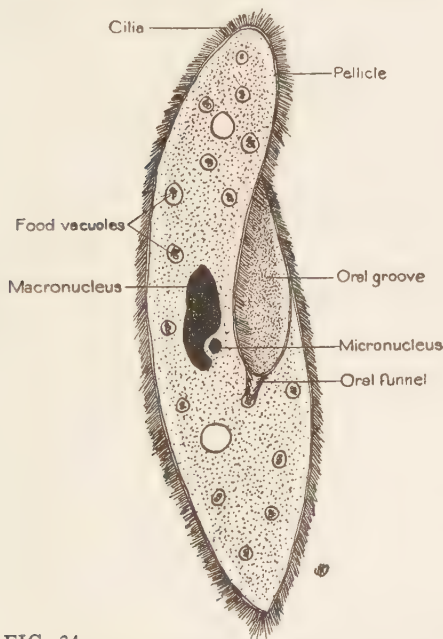


FIG. 24

A single *Paramecium* just before conjugation.

The whole body is enveloped in a thin, tough membrane, the "cuticle" or "pellicle." The pellicle, in turn, is covered with whiplike projections called "cilia," which serve as organs of locomotion. An indentation, the "oral groove," runs along one side of the body from the anterior end to a little past the middle of the cell. This oral groove is lined with powerful cilia, which work the food particles into the groove, whence they pass into a funnel-like depression or "gullet," which leads into the inner mass of protoplasm. The most significant feature of

this single-cell animal is the fact that it possesses two distinct nuclei: a large one called "macronucleus," and a small one called "micronucleus."

If we observe a race of *Paramecia* over a period of several months, we see the individuals undergoing repeated divisions by binary fission. At first the divisions occur daily, but gradually they become less frequent until finally the *Paramecia* cease dividing altogether. At the same time, marked changes are noticeable in the individuals. They appear somewhat opaque, and

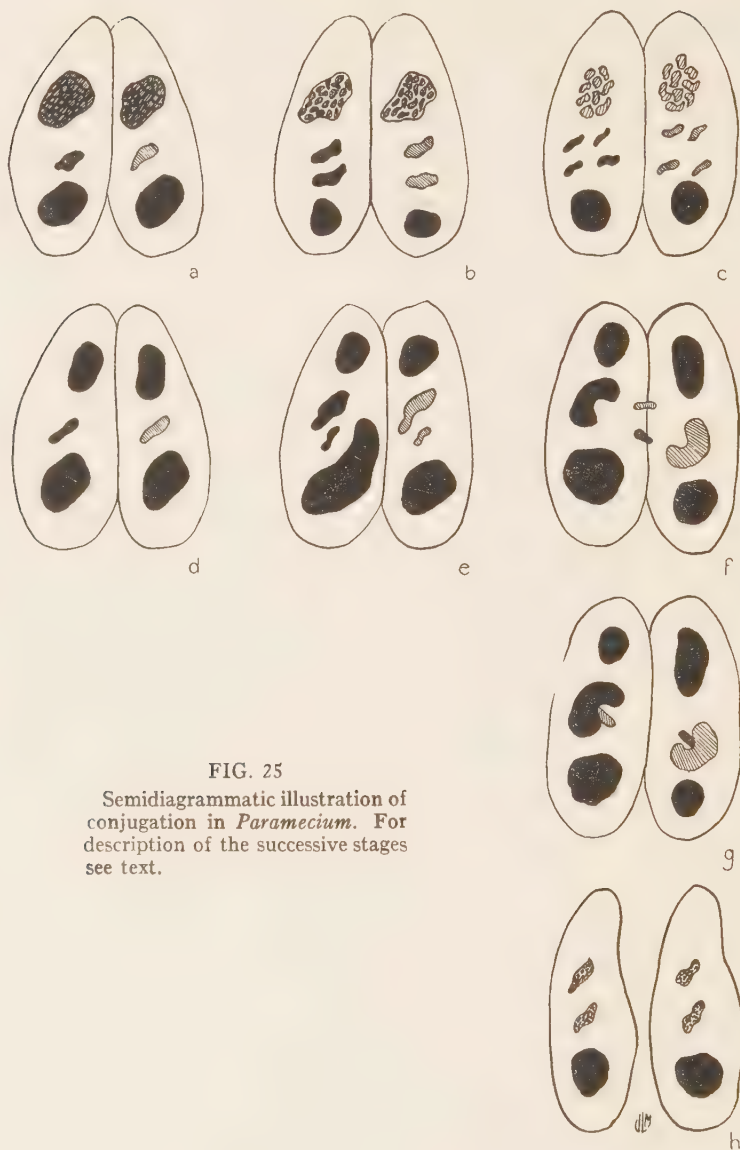


FIG. 25

Semidiagrammatic illustration of conjugation in *Paramecium*. For description of the successive stages see text.

act as though they are excited. The experienced observer understands the meaning of this change. It is the signal for the most remarkable performance on the part of the *Paramecia*—conjugation.

Two *Paramecia* come together and join each other at their oral surfaces. A protoplasmic bridge is formed which unites the internal protoplasm of the two animals (Fig. 25, a). The micronucleus in each individual frees itself from the macronucleus and undergoes two successive divisions. As a result each conjugant has now for a short time four micronuclei (Fig. 25, b, c). Three of these micronuclei in each *Paramecium* disintegrate into the general protoplasm of the cell, and the fourth undergoes still another division. The result of this last division is, however, unequal in that it produces a large and a small nucleus (Fig. 25, d, e). The larger nucleus takes the place of the original macronucleus which by this time has broken up and disintegrated into the protoplasm. Now follows the important step. In each individual, the smaller nucleus migrates across the protoplasmic bridge into the other *Paramecium* where it fuses with the new macronucleus of that individual (Fig. 25, f, g). Here we have an exchange and fusion of nuclear material: the essential element of fertilization in gametic reproduction.

Soon after this fusion of the nuclei the conjugants separate and undergo a series of complicated changes and divisions. The final result is that from each conjugant arise four new individuals, so that the progeny of a single conjugation consists of eight new *Paramecia*. Each of these eight *Paramecia* now enters into a period of binary fission which at first takes place at frequent intervals, but which gradually slows down until the time arrives for another conjugation.

What is the significance of this occasional interruption of binary fission by gametic reproduction? Although the matter is not quite clear, it is generally assumed by biologists, that an occasional formation and fusion of gametes serves as a means of rejuvenation to the race. For instance, it seems that *Paramecia* die if they cannot conjugate for a considerable length of time. One biologist (Woodruff) has been able to keep a race of *Paramecia* from conjugating for over three years by making a daily

change in the culture medium. In this experiment the rejuvenating effect of conjugation was apparently supplanted by the invigorating effect of a continually fresh environment. This would tend to substantiate the theory that conjugation serves as a means of rejuvenation.

GAMETIC REPRODUCTION IN HIGHER FORMS

Gametic or sexual reproduction consists essentially in the union of two differentiated cells called "germ cells" or "gametes." In the higher plants, for instance, the pollen grain, after falling upon

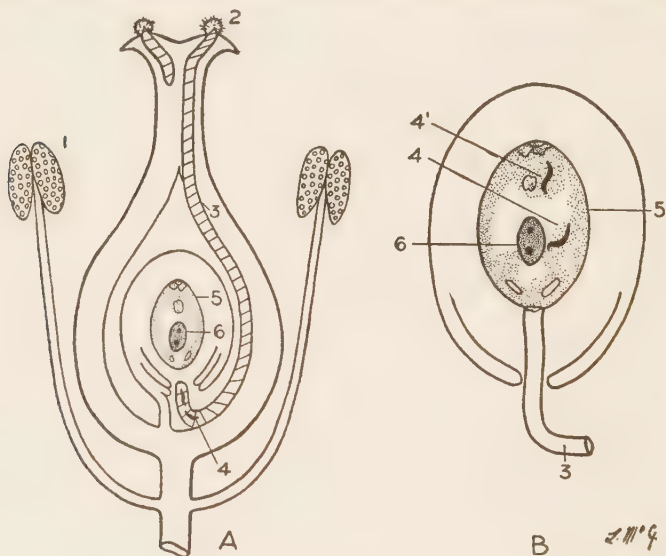


FIG. 26

Diagram of reproductive organs in a flower. 1, anthers; 2, pollen grain on stigma; 3, pollen tube; 4, 4' male gametes; 5, embryo sac; 6, egg. The male gamete at 4 fertilizes the egg whence the embryo develops (modified after Potter).

the stigma, breaks open and a pollen tube bearing two male germ cells penetrates the stigma and travels down through the pistil to the ovary where the two male gametes are deposited into the ovule. Fertilization then results from the union of one of the male germ cells with the egg cell (Fig. 26). In higher animals, the germ cells are even more differentiated. The female gamete is called "ovum" or "egg," while the male gamete is known as "sperm."

Because the egg contains a great amount of food materials for the benefit of the growing embryo, it is, as a rule, much larger than the sperm. This is well illustrated in the eggs of birds and other animals in which the young ones develop outside of the mother's body. A hen's egg may serve as an example (Fig. 41). The egg is surrounded by a hard calcareous shell which protects the egg against enemies and unfavorable conditions. Immediately below there are two other membranes which further protect the egg and hold its contents in place. Below the inner of these two membranes there is a large amount of "albumen," the white of an egg. In the center of the albumen floats a spherical mass of "yolk" which in turn is enveloped by a membrane called the "vitelline" membrane. On top of the yolk, but below the vitelline membrane, a minute white speck can be seen, the "blastodisc." It is this blastodisc which develops and differentiates into the chick during the period of incubation. All other portions of the egg serve the growing embryo as food or as protection.

Even eggs so small that they cannot be seen with the naked eye contain a relatively large amount of food substances. But, no matter how small or how large an egg may be, it is, in the true sense of the word, always considered a single cell.

The sperm, on the other hand, is always extremely small and never contains any food materials. It consists of three differentiated parts: head, neck, and tail. The head contains the chromatin, the neck contains the centrosome, while the tail contains the cytoplasm. Thus the sperm, like the egg, is a true cell.

MATURATION OF GAMETES. Since both egg and sperm are true cells they contain a nucleus. The nucleus of the cell contains, besides other substances, the chromatin, which is the most important part of the cell. It will be remembered that, during the process of division, the chromatin forms the chromosomes, and it will be further remembered that, in all cells of a given species, the number of chromosomes is always the same. If it is true then—as it really is—that egg and sperm are cells, they must contain the same number of chromosomes which is found in the cells of their respective species. If, for instance, the cells of the grasshopper possess 24 chromosomes, the egg of the female grass-

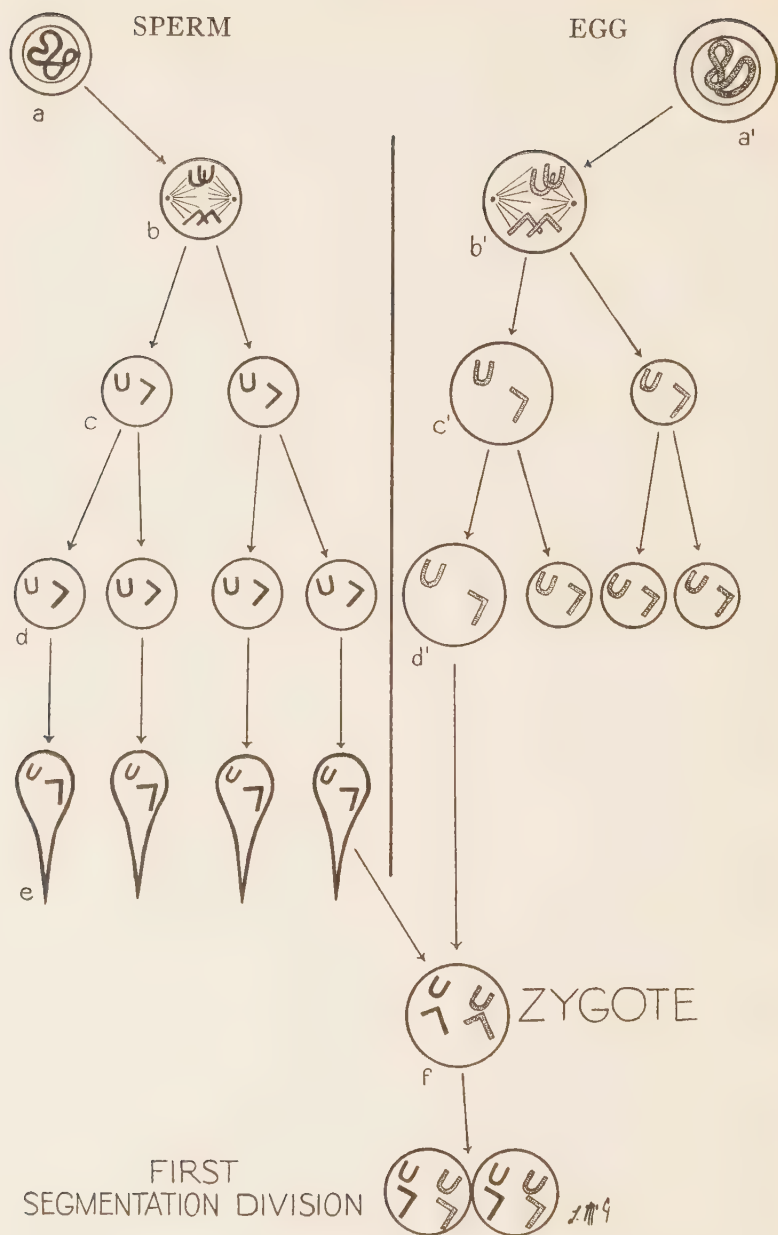


FIG. 27

Diagram showing maturation of sperm cell and egg cell. (For description see text.)

hopper as well as the sperm of the male grasshopper must have each 24 chromosomes. Now, fertilization consists in the fusion or union of the nuclei of egg and sperm. This, of course, would mean that the offspring in its cells would have double the number of chromosomes. In the grasshopper, for instance, the number would be 48, 24 from the egg cell and 24 from the sperm cell. In the second filial generation the number would be doubled again, and so on *ad infinitum*. It does not take much imagination to see that such an increase of chromosomes would soon bring their number to thousands and millions. And yet, it is true that each germ cell is a true cell containing the normal number of chromosomes of their particular kind. What, then, takes place?

To avoid a doubling of the chromosomes with every succeeding generation, the germ cells pass, before they unite with each other, through a complicated process of division. This process is known as "maturation." Its essential feature consists in the reduction of the number of chromosomes to one half. By studying Figure 27 the process may easily be understood. In this figure, we have, on the left side, the immature sperm cell, on the right side, the immature egg cell. (The term "immature" here means simply that the germ cell itself is not quite ready for the act of fertilization though it may be located in an adult and sexually mature body.) The number of chromosomes in our illustration is arbitrarily assumed to be four or two pairs. (It will be recalled that the chromosomes are always arranged in pairs.) For clearness, the chromosomes of the male germ cell or sperm are shown in solid black, while those of the female germ cell or egg are only lightly shaded.

When the germ cell, egg or sperm, gets ready for fertilization, the chromatin of the nucleus runs together and forms a long coil or spireme (Fig. 27, a, a¹). The spireme then breaks into the number of chromosomes, that is characteristic of the given species. In our example, therefore, the number is four or two pairs. This is exactly what takes place in ordinary mitosis or cell division. Meanwhile a spindle has been formed between the two centrosomes (Fig. 27, b, b¹), again as in ordinary cell division. Now comes an important difference in the behavior

of the chromosomes. In ordinary cell division (mitosis) the chromosomes arrange themselves in a starlike figure in the center of the cell; in reductional division the members of each pair of chromosomes come together in such a way as to lie one on top of the other. This is illustrated in Figure 27, b, b¹. After remaining in this intimate union for a short time, the chromosomes separate without dividing as they do in ordinary cell division. The result is that only two chromosomes travel to each pole of the cell. This means that the two daughter cells receive not the *complete number of chromosomes, but only half the number*, two in our example. Notice further, that each daughter cell received one member of each pair of chromosomes as can be seen readily by studying Figure 27, c, c¹.

The difference between the reductional division of the germ cell and the division of ordinary body cells is diagrammatically illustrated in Figure 28. In this diagram, the chromosomes of both the germ cell on the right side and a body cell on the left are represented by the capital letters A and A₁, B and B₁. We assume, therefore, four chromosomes arranged in two pairs. By following the various stages on the left of the diagram, it will be seen that the result consists of two cells, each cell having the same number and the same kind of chromosomes as the original single cell. By following the succeeding stages on the right side of the diagram, it will be noticed that the result of the division consists also of two cells, but each cell has only two chromosomes instead of four. Furthermore, the chromosomes are not from one and the same pair, but there is one chromosome from each pair in the two germ cells. In other words, one germ cell received chromosome A from pair A A₁ and chromosome B from pair B B₁. The other germ cell received chromosome A₁ from pair A A₁, and chromosome B₁ from pair B B₁.

It may be recalled that the two chromosomes making up a pair represent respectively the paternal and maternal contributions of the preceding generation. If chromosome A came from the paternal side, then its mate chromosome A₁ represents the maternal contribution. Thus it becomes clear that during reductional division or maturation the *corresponding contributions of the two parents go to different and separate germ cells*. The

Cell Division

Maturation Division

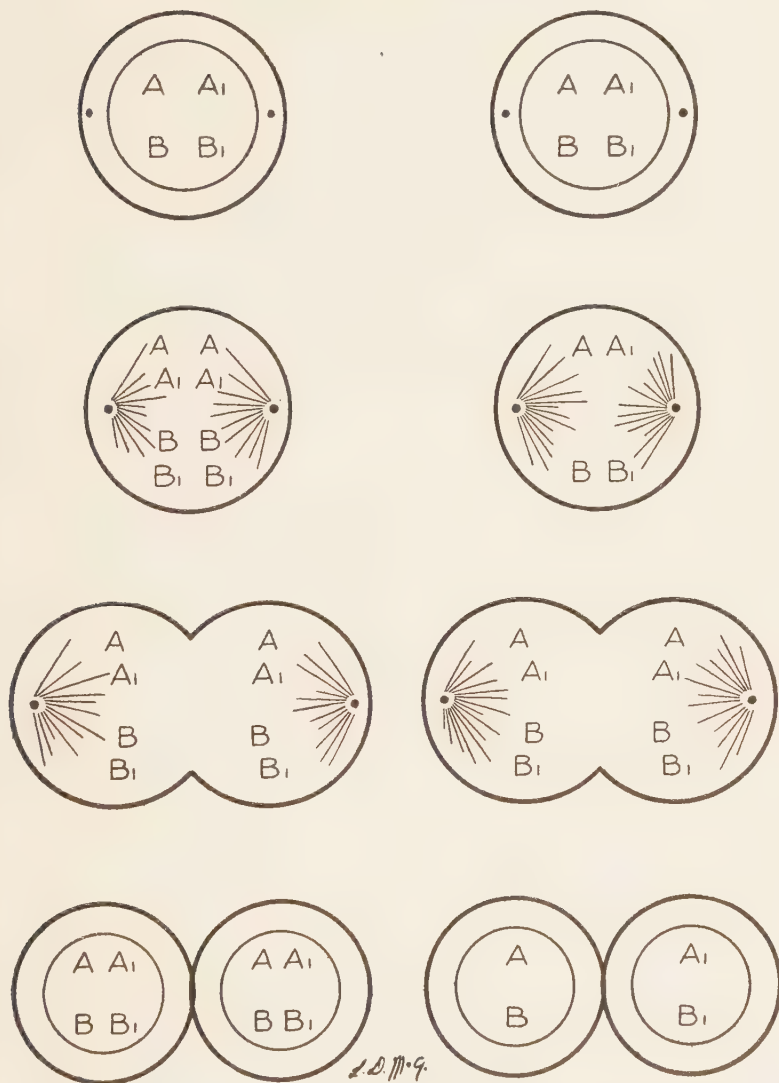


FIG. 28

Diagram showing the difference between ordinary cell division (mitosis) and reductional division of the germ cells.

understanding of this distribution of paternal and maternal chromosomes to separate germ cells is essential in the study of heredity.

Let us return once more to the study of Figure 27. After the reductional division is completed, there are two sperm cells and two egg cells each with half the number of chromosomes. Such germ cells are known as "secondary spermatocytes" and "secondary oöcytes" respectively (Fig. 27, c, c¹). Each of these now undergoes another division with the result that four sperm cells and four egg cells are present. This last division, however, is *not of a reductional nature*, so that each of the four sperm cells as well as each of the four egg cells still possesses half the number of chromosomes (Fig. 27, d, d¹). The four sperm cells, which at this stage are called "spermatids," now enter a period of metamorphosis during which they gradually assume a long, slender form which is best adapted for penetration into the egg cell (Fig. 27, e).

Turning our attention now to the four egg cells (Fig. 27, d¹), we notice that there is a great difference in their size. One is large, in fact as large as the original immature egg cell, while the other three are extremely small. This difference in size is due to the fact that, in the two divisions, one egg cell received all the cytoplasm and inclosed food material from the original immature egg cell, while the other three received none at all. It is not surprising to find that only the large one is functional; that is, capable of becoming fertilized. The other three are nonfunctional and very soon disintegrate.

At the end of the period of maturation, we have then four functional sperm cells, but only one functional egg cell. All of them, however, contain half the number of chromosomes which is characteristic of their species.

THE ZYGOTE. One mature sperm cell (spermatozoön) now penetrates into the functional egg which then possesses two distinct nuclei: its own and the nucleus of the sperm (Fig. 27, f). This is the act of fertilization and the beginning of a new organic life. In this condition, the fertilized egg is known as the "zygote." A zygote is therefore the first stage in the development of a new organism. It may be well to look a little closer into the make-up

of the zygote. Although the egg contributes all the cytoplasm and food materials, the important and essential parts come in equal proportion from the two parents. Each parent brings an equal amount of chromatin in the form of half the number of chromosomes, restoring thus in the zygote the normal number of chromosomes. Still more remarkable is the fact that in the zygote not only the *normal* number of the chromosomes is restored, but also their *paired condition*. For each kind or type of chromosome in the egg cell, the sperm brings an exact mate or counterpart as can readily be seen in Figure 27, f. The zygote, or fertilized egg, is thus seen to be a *double being*, one half coming from the paternal, the other half from the maternal side. And since the contribution of each parent consists of the *same kind of chromosomes*, it must be clear that the zygote is a *double being* in the sense that it possesses every trait or character of the future individual in double dosage. To make this clear, let us have a final look at the zygote in Figure 27, f.

There are four chromosomes, two solid black ones from the sperm and two lightly shaded ones from the egg cell. These chromosomes can be arranged into two pairs in such a way that each pair consists of two exactly equal mates of which one came from the sperm and the other from the egg. It is reasonable to assume that the two mates, being exactly alike, carry determiners for the same traits. If, for instance, the black L-shaped chromosome of the sperm carries a determiner for the color of the hair, then its mate, the lightly shaded L-shaped chromosome from the egg, carries likewise a determiner for hair color. The zygote thus contains two determiners for hair color, one from the sperm and one from the egg. If now, following up our example, the two determiners happen to be for the same hair color, then the new individual will be a "pure bred" as regards color of hair. If, on the other hand, the determiners happen to be for different colors, the new individual will be a "hybrid" with regard to the color of its hair. The same holds true for every trait or character of the future individual. This is the basis of the so-called Mendelian laws of heredity and explains how an unfertilized egg, although it has lost half the number of chromosomes during the maturation division, can still develop into a full and normal individual, as is

MALE



FEMALE

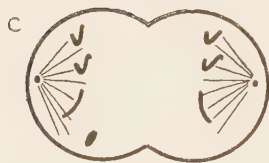
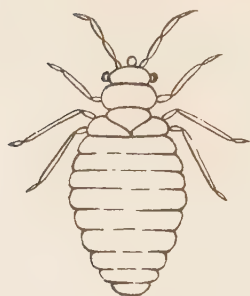


FIG. 29

Diagram showing the behavior of the X chromosome during reductional division (modified after Goldschmidt).

the case with the unfertilized eggs of the common hive bee, which develop into the males, or drones.

SEX DETERMINATION. How do we know that the chromosomes carry the determiners of heredity? The answer to this question will afford us an opportunity to correct an error which, up to the present, has been allowed to stand for the sake of clearness. Several times the statement has been made that the chromosomes in a cell are paired, that their number, in other words, is always an *even* one. The cells of the grasshopper, for instance, have been said to contain 24 chromosomes. Now this is not quite correct, for the cells of the male grasshopper have only 23 chromosomes. What is true of the cells in the grasshopper is true of the cells of many other animals. In some forms, the cells of the male have the uneven number of chromosomes, in other forms the cells of the female. At any rate, there is in the cells of one sex of these animals one chromosome which is not paired, and, for this reason, it is called the "odd" chromosome. It is also known as the "X" chromosome and—this is letting the cat out of the bag—"sex" chromosome. This "odd" chromosome, in other words, carries the sex determiner. By studying Figure 29, which illustrates the maturation of the germ cells in a bug, the matter will become clear.

The cells of the bedbug contain eight chromosomes in the female and seven in the male. The male, therefore, has the "odd" chromosome. When the germ cells of this insect pass through reductional division at the time of maturation, each "secondary oöcyte" gets four chromosomes, that is, half the original number (Fig. 29, d¹). With the "secondary spermatocytes," however, the outcome is different. One receives four chromosomes, the other only three (Fig. 29, d). The reason is clear. In reductional division, the chromosomes, instead of dividing as in ordinary cell division, separate in such manner, that the mates of each pair travel to separate germ cells. Since the "odd" chromosome has no mate, it stands to reason that only one of the two secondary spermatocytes will receive an "odd" chromosome. There are therefore two kinds of sperms, but only one kind of egg. This gives two possibilities with regard to fertilization. Either a sperm containing the "odd" chromosome will fertilize the egg, or the egg will be fertilized by a sperm without the "odd" chromosome. In the first

alternative, the result is a zygote with an even number of chromosomes—a female. In the second instance, the result is a zygote with an uneven number of chromosomes—a male (Fig. 29, e). The determination of sex is, therefore, dependent on the presence or absence of the “odd” chromosome: if present the result is a female, if absent the result is a male.

Since the two kinds of sperms—with or without the “odd” chromosome—are present in equal numbers, and since, under ordinary conditions, one kind has just as much chance to fertilize an egg as has the other, it is only logical that the ratio of the two sexes should always be approximately 1 to 1.

The reader might by this time have thought of several cases in nature which do not seem to harmonize with our statement regarding sex determination. What, for instance, of the many examples among insects where males develop from unfertilized eggs? This is a very good objection, since it will serve to clear up a few other difficulties as well. To simplify things, let us choose a concrete example.

There is a group of insects, called “aphids,” commonly known as “plant lice,” whose life history is very interesting and instructive. Most plant lice pass the winter in hard-shelled eggs laid on plants during the previous autumn. From these eggs are hatched, in the spring, young insects which grow into wingless females known as “stem mothers.” There are no males for these “stem mothers” to mate with, but they have the power of producing young which, developing from unfertilized eggs within the mother’s body, are born in an active state, and may themselves become capable of reproduction after less than two weeks’ growth. Thus successive generations of females are rapidly produced during the spring by means of virgin birth (parthenogenesis). Soon or later, a brood of young insects arise, which grow into winged aphids. Such winged plant lice can leave the plants on which they were born and migrate to others where there may be a more abundant food supply. Thus through spring and summer the virgin generations succeed each other until, with the arrival of autumn, males as well as females are born from the unfertilized eggs. These males and females mate and produce fertilized eggs whence next spring’s “stem mothers” will be hatched.

In the life history of these plant lice there occur several stages which do not seem to harmonize with our statements in regard to fertilization and sex determination. These apparent contradictions are: (1) that unfertilized eggs develop for several generations into new insects of *one sex* (female) only; (2) that suddenly (in autumn) from similar unfertilized eggs both *males* and *females* arise; (3) that, in the spring, fertilized eggs produce only *females* (the "stem mothers"). However, a careful examination of the germ cells, from which the various generations arise, will solve these difficulties quite nicely.

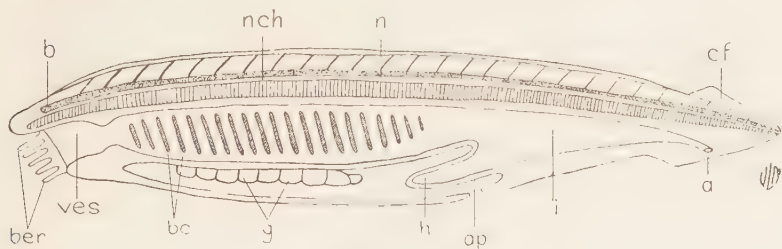


FIG. 30

Transparent view of *Amphioxus lanceolatus*. b, brain; nch, notochord; n, neural tube; cf, caudal fin; ber, buccal cirri; ves, vestibule; bc, branchial clefts; g, gonads; h, liver diverticulum; ap, atriopore; i, intestine; a, anal opening.

1. If we should examine the eggs from which the successive virgin generations are born, we would see, to our surprise, that these eggs do not undergo the process of maturation at all. This, of course, means that the unfertilized eggs, at the time of development, possess the complete number of chromosomes. Now, the complete number of chromosomes in these female insects includes paired X chromosomes. Paired X chromosomes, as we already know, determine femaleness. Hence it is clear why only females arise from such unfertilized eggs. But one may ask, how, in the first place, are unfertilized eggs capable of development at all? For clearness, the answer to this question must be deferred for a short time.

2. In the last autumn generation, there arise from similar unfertilized eggs males as well as females. An examination of these virgin eggs reveals that shortly before their development a number of eggs throw out one chromosome. Further examination

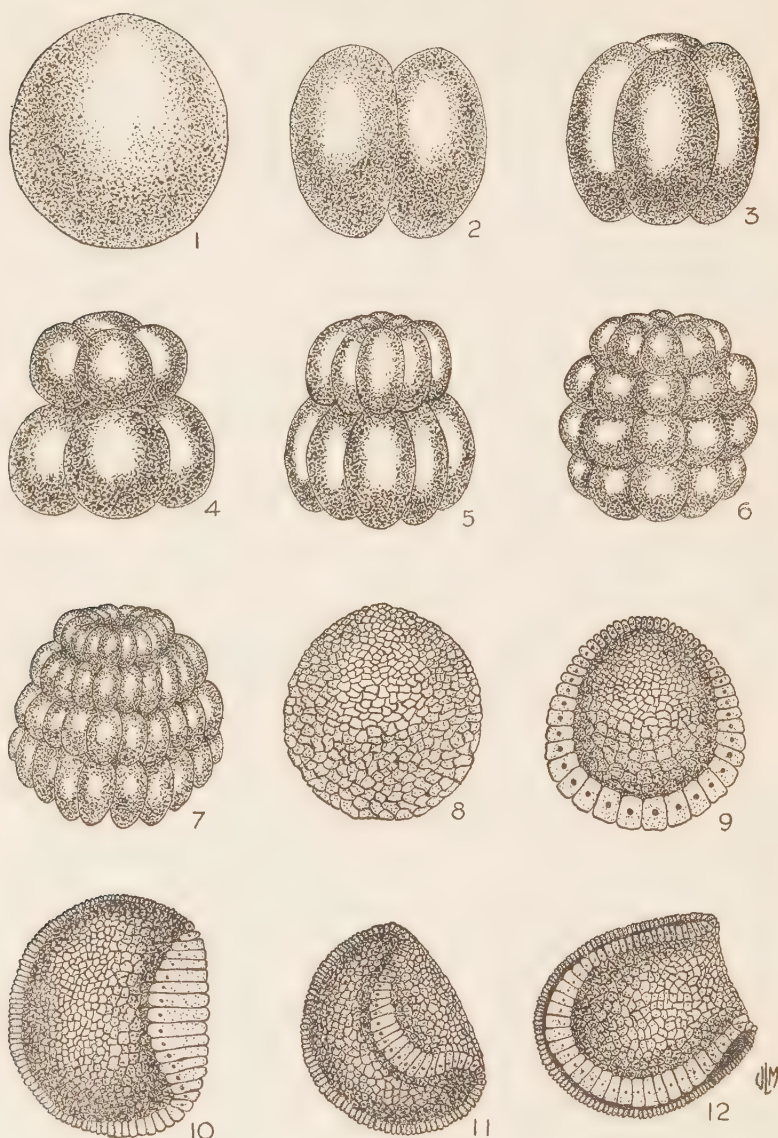


FIG. 31

Segmentation of *Amphioxus* egg. 1, fertilized egg or zygote; 2, 2-cell stage; 3, 4-cell stage; 4, 8-cell stage; 5, 16-cell stage; 6, 32-cell stage; 7, 64-cell stage; 8, blastula external view; 9, section of blastula; 10, beginning of gastrula; 11, advanced stage of gastrula; 12, final stage of gastrula; (after Jewel Models).

shows that the expelled chromosome is an X chromosome. Thus a number of eggs possess an uneven number of chromosomes, and these are the eggs from which the males develop.

3. The sperms of the male plant lice now fertilize the eggs of the females. In order that the number of chromosomes may remain constant, the germ cells partaking in this fertilization must pass through a reductional division. This they actually do. Now we know that reductional division results into two kinds of mature sperm cells, one kind containing an "odd" or X chromosome, the other kind being without it. There should therefore in the spring arise males as well as females. However, for reasons not understood, the sperms lacking the X chromosome disintegrate shortly after maturation, leaving the sperms with the X chromosomes to fertilize the eggs which themselves, of course, all contain an X chromosome. All resulting zygotes have therefore paired X chromosomes, which determine, as we know, femaleness. Whence we see why, in the spring, only females (the "stem mothers") arise from the eggs which were fertilized in the previous autumn.

PARTHENOGENESIS. The development of eggs without fertilization is known as parthenogenesis, or virgin birth. Why the eggs of some forms can develop without fertilization, while others cannot, or at least do not develop without previous fertilization, remains one of the unsolved problems in biology. In a few species, parthenogenesis is the normal form of reproduction, although in most cases, after a few parthenogenic generations, a sexual generation follows in which the eggs are fertilized in the usual way.

Some years ago Loeb made the discovery that the eggs of some marine animals could be stimulated to develop without fertilization if they were placed in sea water to which were added certain amounts of salts. Loeb also found that the unfertilized egg of the frog could be made to develop by pricking the surface with a very fine needle. Whether artificial parthenogenesis, as such cases are called, can be induced in the higher forms, is at the present time a mere speculation.

DEVELOPMENT OF ZYGOTE INTO EMBRYO. As stated before, the zygote, or fertilized egg cell, is the beginning of a new organic life. Biologically speaking, the individual begins its life at that moment. Development now sets in, that is, the zygote undergoes a

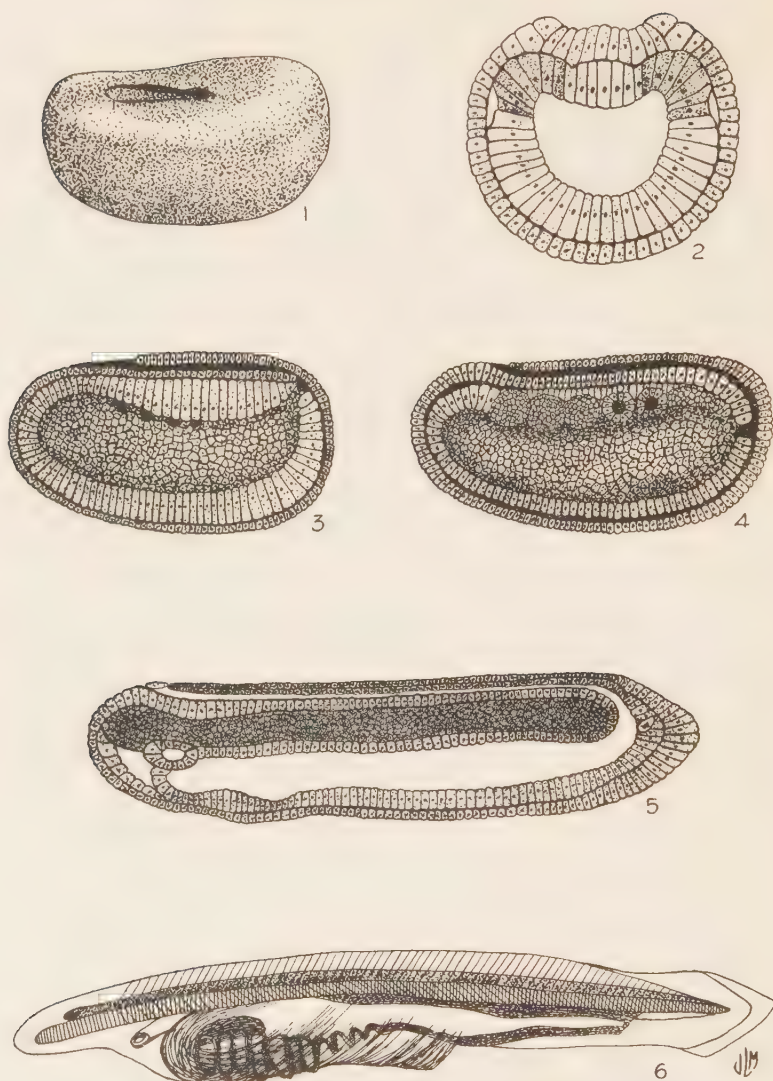


FIG. 32

1, Elongated gastrula with neural groove; 2, cross section through neural groove; 3, longitudinal section through embryo with four somites; 4, longitudinal section through embryo with about 5 pairs of somites; 5, optical section of embryo with about 12 pairs of somites; 6, embryo and branchial clefts showing segmental arrangement of muscles, (1, 2, 3, and 4 after Jewel Models; 5 and 6 after Bonnet).

long series of mitotic divisions during which it gradually differentiates into the adult form. It may be well here to pause a moment and consider the word "differentiate." Let us remember that the zygote is a single cell, although its nucleus has been derived from two distinct sources. This single cell grows into something which is made up not only of a great number of cells, but consists of many *different kinds* of cells as well. The one cell becomes many cells and at the same time gradually changes into different types of cells. This is diagrammatically illustrated in Figure 42. By following down the successive divisions on the right-hand side of the diagram, you will note that the cells become more and more transformed into the various types of cells which constitute the tissues of the adult organism. Some of these cells develop into long, slender muscle cells, others into closely compact bone cells, others into long nerve cells with many processes, still others into the various types of epithelial cells. In other words, the single germ cell not only develops into a great number of cells, but at the same time changes into different types of cells. The transformation of cells which leads to the formation of tissues, is known as *differentiation*. How such differentiation is accomplished is a question about which we know very little. It constitutes one of the most remarkable properties of living protoplasm, and has been the object of intense research by many investigators. The ability of differentiation inherent in the protoplasm of every germ cell is probably the greatest stumblingblock in the way of a successful mechanistic explanation of living matter.

It is beyond the scope of this work to go into the further development of the zygote. Figures 31 and 32 show the reader successive stages in the development of *Amphioxus lanceolatus* (Fig. 29), a small, fishlike animal which occurs in the shallow waters of almost any seashore.

CHAPTER VI

ENVIRONMENT AND HEREDITY

The study of heredity is very often called the "central problem" of biology. It is so called for two reasons. The first reason is based on its great practical and humanitarian value: practical, because it plays such a great part in the activities of the stock breeder and agriculturalist; humanitarian, because it enters largely into the problems of the sociologist, pedagogue, and parent. The second reason, which is the more important one for the professional biologist, is based on the relation between *organic evolution* and *heredity*. From this aspect, the study of heredity becomes a very technical problem involving such debatable questions as the origin of new variations in the germ plasm and their effect on the following generations.

Here we consider the problem more in the light of the first reason. In either case, however, it is first necessary to obtain a clear notion of what is meant by the term *heredity*.

WHAT IS HEREDITY?

Suppose you found yourself in a large hall where there are assembled several thousand men from the same city, you would undoubtedly notice the great difference in their respective statures. Now suppose you could conveniently line these men up in a military fashion, with the shortest at one end, the tallest at the other, while all intermediary sizes would be arranged in proper order between these two extremes, you could understand what the biologist means when he speaks of "variations" within a group or population. Such an idea occurred to a man named Quetelet. Some years ago, he measured accurately 25,878 American soldiers. Then he arranged these measurements in a line, beginning with the shortest, 60 inches, and ending with the tallest, 76 inches. Under each number he wrote the number of soldiers who were of that particular height. Here is the result:

Sizes in Inches																
60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
Number of Soldiers per 1,000																
2	2	20	48	75	117	134	157	140	121	80	57	26	13	5	2	1

By studying this table a little closer, you will observe that the greatest number were 67 inches tall. By comparing the numbers on the right and left of the figure 157 you will notice a certain symmetry. There are about as many soldiers 66 inches tall as there are soldiers 68 inches in height, about as many 65 inches tall as there are 69 inches tall, about as many 64 inches tall as there are 70 inches tall, and so on. When a trait appears in a group or population in this fashion it is called a "variation." The point at which we have the greatest number of individuals represented, is called the "average" or "mean" of the variation. In our example, this was 67 inches. The figures or types on the right, (68, 69, 70, 71, 72, 73, 74, 75, and 76 inches) are called the "plus variants" because they are more than the average, while the figures or types to the left, (66, 65, 64, 63, 62, 61, and 60 inches), are called the "minus variants" because they are less than the average.

You will remember that our example called for an assembly of several thousand men from the same city. By that we intended to keep track of a very important point. The individuals of our own particular group or race must all belong to a "pure" race. We may thus use our same example in another way. You know that, in Africa for instance, there are negro tribes, called "pygmies," whose members are smaller than the smallest people among the Anglo-Saxons. Suppose, then, we had several thousand people whom we wanted to measure in regard to their respective sizes and half of these were Anglo-Saxons and the other half were pygmies, our variation would be altogether different, in fact nothing at all like the one we have just been considering. The reason would be that the group did not represent a "pure" race in regard to tallness and shortness.

Characters or traits which act in this manner within a pure race are called "continuous variations." Such characters may have nothing to do with heredity, but may be the result of environmental conditions. Thus we are brought face to face with another problem: *environment versus heredity*.

ENVIRONMENT VS. HEREDITY

To bring out the relation between the two, let us, with Professor Goldschmidt, perform a few experiments.¹⁷

You and I will for a short time become truck farmers. We are the owners of a little farm where we raise mainly vegetables for the folks in the big city. One of the most important vegetables under cultivation is beans. Now we have three classes of customers: one class which likes to have everything real small and dainty; the second class, the solid middle class, which likes to have things neither too small nor too big, but prefers the happy medium; the third class of customers has for its slogan, "The Bigger the Better!"

AN EXPERIMENT. We raise, therefore, three different varieties of beans: small, medium size, and large. For our first variety, we employ as seeds, beans which measure exactly 10 mm. in their length; for the second, we use beans measuring exactly 15 mm.; and for our third variety, we use beans which measure exactly 20 mm. We now plant these three different kinds of beans in separate plots, the soil of which we know is of uniform, average quality. After giving all our plantings the same care, we gather our crop in the late summer, and carefully measure again the beans which we gather from each of the plots. To our surprise we find that the beans of the first plot are not all 10 mm. long. A goodly proportion is considerably smaller, while a great percentage is considerably larger (Fig. 33, a). A similar variation is found in the beans which we gather from the second and third plots.

In the second plot, we have a variation from 11 mm. to 19 mm., though most of the beans will be close to the original size of 15 mm. (Fig. 33, b). In the third plot, we notice a variation of from 16 mm. to 24 mm., though again most of them will be close to the average size, namely 20 mm. (Fig. 33, c). In each of these three instances, we started with an exactly uniform heredity, and in each we end with quite a variable result. What is the explanation of this diversity—diversity in end product or result, in spite of the uniformity of heredity? The answer is *environment*. Although by supposition the soil of the three plots was of average uniformity, and although we gave the three plots the

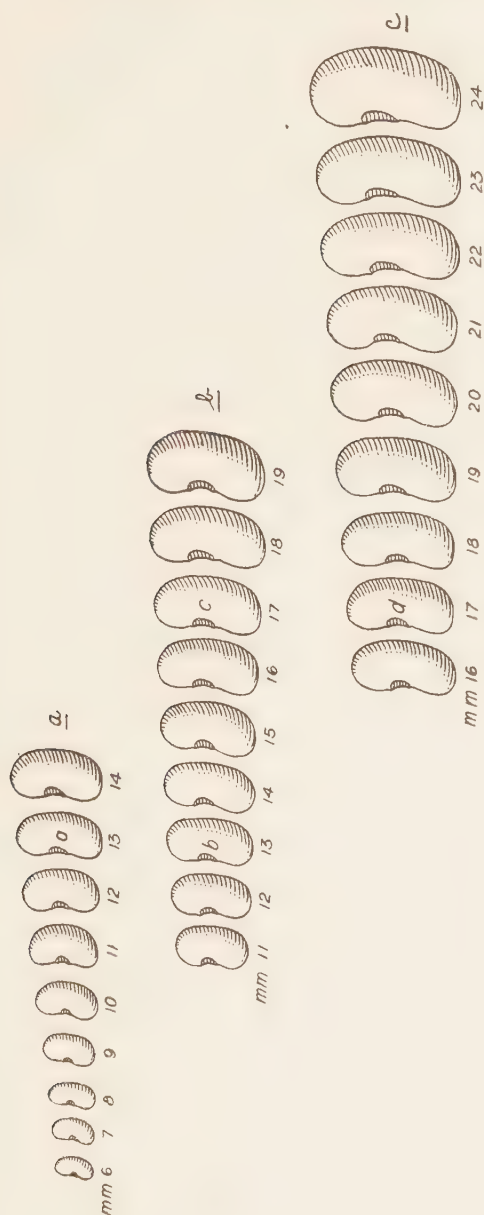


FIG. 33

Three varieties of beans. (Redrawn from Goldschmidt's *Die Lehre von der Vererbung*, Verlag von Julius Springer, with permission of author and publisher.)

same normal care, there are enough differences in the environmental conditions to cause these variations in size. *This* seed obtained a little more nourishment from the soil than its neighbor did; *another* one is unfortunate enough to land on a pebble as large as itself.

What then does the result teach us? Simply this: that, even under average normal conditions, environment does influence and modify the development of heredity. We have illustrated a very important principle; namely, environment puts its stamp on heredity.

Let us try another experiment. This time we fix up two separate plots. One plot is in a pleasant sunny spot and we cover it with rich soil to which we add a goodly amount of the best fertilizer; in other words, we create "ideal conditions." With the second plot we do exactly the opposite: we select a shady spot, cover it with the poorest soil and give it as little fertilizer as possible. Here, then, we create "extremely poor environment." Now we select beans from our medium-size variety, taking only those which measure 15 mm. Thus we plant the same kind of beans in the two plots. To the ones in the plot with the ideal conditions, we give excellent care, to the ones in the poor plot, we give as little care as possible. Now let us see how strong heredity is, or the other way around, what difference an extreme environment can make.

TWO IMPORTANT PRINCIPLES

Note the amazing result (Fig. 34). The harvest of beans from the ideal plot is beyond all expectation. Not only are these beans larger than the average size of their own race, but most of them are considerably larger than the largest one of their own race. Then look at the crop from the poor plot. Exactly the opposite result! Not only do we have smaller beans, but most of them are considerably smaller than the smallest ones of their own race. What lesson can we draw from the outcome of this experiment? It drives home to us two very important principles. *First, that the offspring of average parents can, by exceptionally good environment, be raised considerably above its hereditary level, and similarly, the offspring can, by exceptionally poor environment, be considerably lowered beneath its hereditary level.* Now substi-

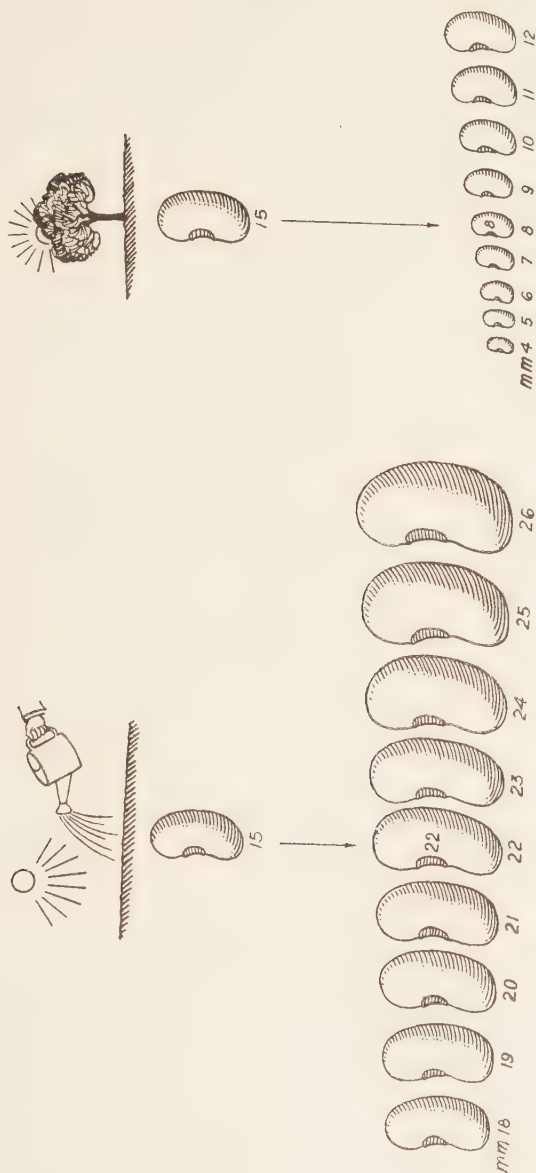


FIG. 34

Experiment showing influence of environment. (Redrawn from Goldschmidt's *Die Lehre von der Vererbung*, Verlag von Julius Springer, with permission of author and publisher.)

tute good home environment for the good condition of the soil in the first plot, and substitute bad home environment for the poor condition of the soil in the second plot, and further substitute training and education for the good care we afforded the beans of the first plot and substitute lack of training and education for the neglect we showed the beans of our second plot—and draw your own conclusions.

The second important principle brought out by this experiment may be stated thus: *As a rule, it is not correct to say that this or that trait or characteristic is the result of heredity, but rather we must always say that it is the result of heredity in such and such an environment or under these or those conditions. No heredity can exist, much less develop, outside of an environment, and every environment leaves its mark on every hereditary trait.* At first glance, it may seem somewhat foolish to argue about the relative importance of heredity and environment. The one, evidently, cannot exist without the other. It almost seems like arguing whether the stomach or the food is of greater importance; without the one the other is of no avail. And yet, the matter has quite another angle to it. The physician may be unable to cure a diseased stomach, but the dietitian may, nevertheless, give much help to a diseased stomach. So with our present problem. While, theoretically, heredity is just as important as environment and vice versa, still it is quite a different problem when we are called upon to improve or control them. And it goes without saying that it is much easier for us to influence environment than it is to influence heredity. That is why environment will always be the more practical—and, therefore, the more important phase of the two for the sociologist, the pedagogue, and even the physician.

ANOTHER EXPERIMENT. Let us return to our farm and beans for another experiment. Having obtained, in our last experiment, such wonderful quantitative results by planting beans in good soil, it is only natural that we should hope further to improve on the size of our variety. So we take the largest beans of that crop; namely, the ones measuring 26 mm. and plant them in the same favorable or even better environment. Do we get a still bigger race? No, we do not (Fig. 35). We have not been able to im-

prove further on the size of our beans. We get quite a similar harvest: our beans show a variation of from 18 mm. to 26 mm. *We have learned that there is a limit to the influence of environment.* No matter how often we select these largest beans for

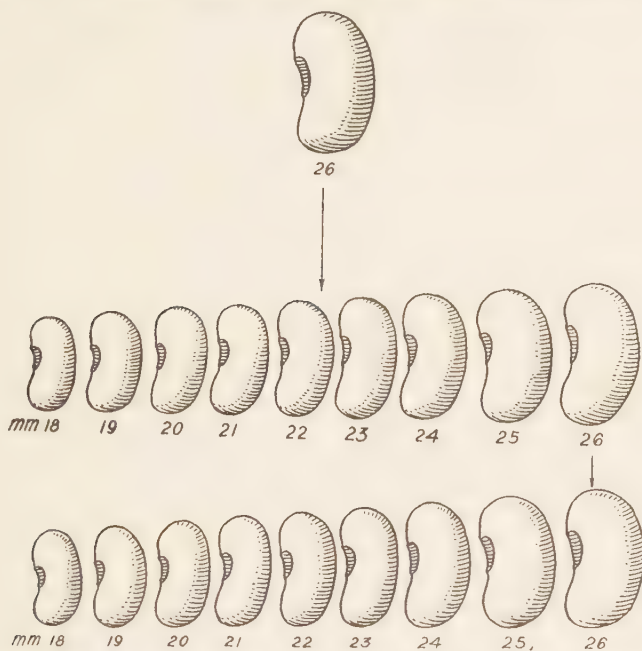


FIG. 35

Experiment showing that there is a limit to improvement through environmental conditions. (Redrawn from Goldschmidt's *Die Lehre von der Vererbung*, Verlag von Julius Springer, with permission of author and publisher.)

planting in favorable soil, they will not grow bigger. In other words, *there is a limit to improvement inside of a pure race.* The only way we could further improve the size of these beans would be by crossing them with others of their kind but of a still larger variety, a method commonly employed by plant and animal breeders.

ENVIRONMENTAL TRAITS NOT INHERITED

You will recall that we obtained large beans by putting them in an especially favorable environment, that is, in an environment which was better than the usual type. It would prove

rather expensive to keep up our method, for our expense would eat up any profit we might be able to make from the larger beans. Therefore we plant the largest beans next season in the ordinary environment of our farm, hoping that the size, once present, will remain. But, again, we are disappointed (Fig. 36). The beans not only do not grow as large as the ones planted, but have ac-

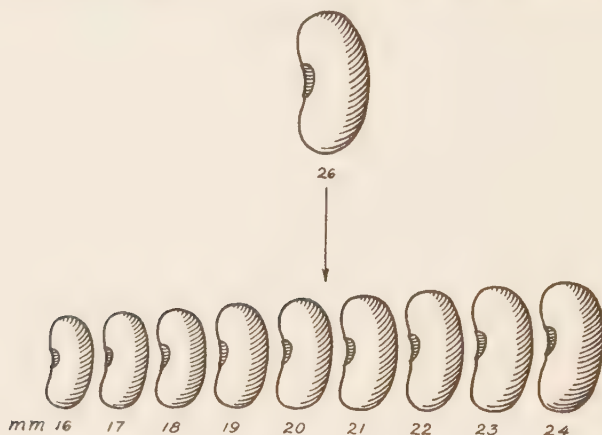


FIG. 36

Experiment showing that environmental traits are not inherited. (Redrawn from Goldschmidt's *Die Lehre von der Vererbung*, Verlag von Julius Springer, with permission of author and publisher.)

tually gone back to the original size of the third variety, that is, again they vary from 15 mm. to 24 mm. Although we are disappointed, we have learned one of the most important principles about heredity: *Conditions imposed on the individual by environment are not inherited; they do not become part and parcel of the race as such, but unless the same environment is kept up, disappear in the next generation.* This principle is at once the hope and despair of the pedagogue and sociologist, for it discounts both good and bad environment as a hereditary factor.

Now let us have one last look at the beans which have been so useful to us. Notice in Figure 33 that in the first and second variety there are some beans which have exactly the same size; namely, 11, 12, 13, and 14 mm. The same is true of the second and third varieties, among which we have beans measuring 16, 17, 18,

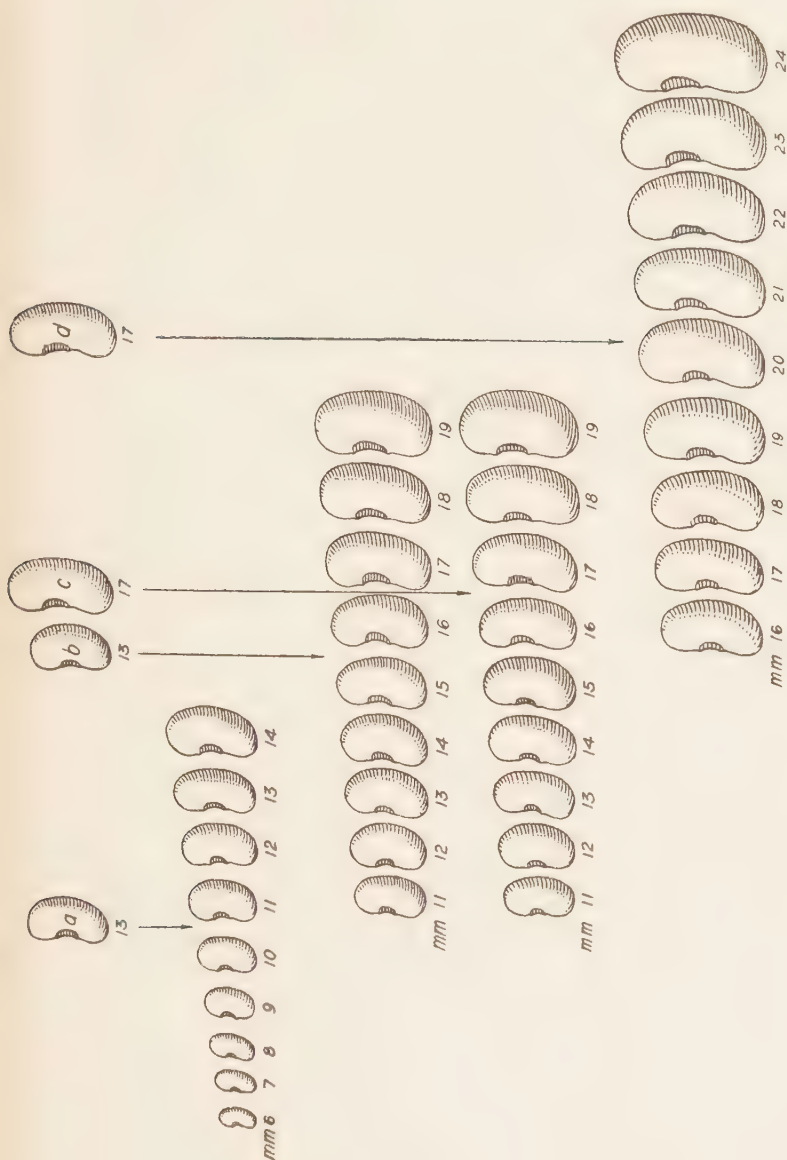


FIG. 37

Experiment showing that mere appearance is not a criterion of hereditary contents. (Redrawn from Goldschmidt's *Die Lehre von der Vererbung*, Verlag von Julius Springer, with permission of author and publisher.)

and 19 mm. Now suppose we take a little sack of beans all measuring 13 mm. Could we tell from just their appearance to which variety they belong? No, we shall have to plant them, and measure their offspring. Some of the 13 mm. seeds produce beans with a variation of from 6 to 14 mm., while others produce offspring with a variation of from 11 to 19 mm. (Fig. 37). This difference in the offspring could not have been foreseen from the mere appearance of the parent seeds. Thus we *see that heredity is not always visible, and that mere appearance is not a criterion of hereditary contents*. This last principle is strikingly illustrated in several abnormalities which run in certain families, such as color-blindness and hemophilia. Let us take the latter for example. Hemophilia, or bleeders' disease, is the peculiar condition where the blood does not properly coagulate. The blood consists of a liquid or plasma in which a great number of different kinds of corpuscles float about. It is quite like a small but fast-streaming river in which a great number of different kinds of fish are swimming about. The different kinds of fish here represent the corpuscles. The water of the river corresponds to the liquid or plasma of the blood. This plasma normally contains a substance called "fibrin," which forms a clot when exposed to air. In other words, when we cut or injure a blood vessel, this substance in the blood really forms a natural cork on the wound thus stopping the flow of blood. Complete or partial lack of this fibrin seems to be a hereditary condition in those families and individuals known as bleeders. The peculiar feature in regard to hemophilia is the fact, that, although the daughters of a hemophilic father are not bleeders themselves, they, nevertheless, carry the hereditary factor of the disease and give it to half of their sons and half of their daughters. The "afflicted" sons are actual bleeders like their grandfather, while the "affected" daughters are again only carriers of the disease (Fig. 43).

DEFINITION OF HEREDITY

Up to this point, we have used the term heredity without any detailed explanation as to its scientific meaning. We have been referring to the beans which we used as seeds in our various experiments as the heredity of our next generations. Now let us ask

ourselves an apparently simple question: What are these seed beans? They are first *the fruit of the previous generation, and secondly, the beginning of the next succeeding generation*. Now we'll substitute our terms and say that *heredity is the genetic connection between two successive generations*. Suppose that last year your gardener raised some very beautiful asters, and that this coming spring you should like to raise some yourself. Therefore you go to the gardener and ask him for a handful of the seeds he obtained from those beautiful flowers. The handful of aster seeds thus represents the fruit of last year's asters and the beginning of next summer's asters; you are in reality carrying in your hands the connection between the two generations, the heredity of the asters you hope to have in summer.

If we want to know the full meaning of heredity, we have but to find out what it is that is contained within this connection. It is not enough for us simply to look at the outside of the seeds, but we must, so to speak, open the container to see what is within. To do this, we shall have to recall here again what we learned about the structure of the cell. Remember our comparison of a balloon filled with the unboiled white of an egg, in the center of which there floated a smaller balloon filled also with the raw white of an egg. In the latter, we imagined a string of beads closely set together and twisted about in an irregular network. For our present purpose, we have to concentrate our attention on that network of beads. As you recall, this network is known as "chromatin" because it will take a dye or a stain much more readily than do the other parts of the cell. You may further recall the statement that not only is every organism made up of a greater or smaller number of cells, but that every living being starts its organic life as one such single cell. This one single cell divides into two, these two each into two so that there are four. Each of the four then divides into two, thus making eight cells, and so on until that number of cells is reached which make up the whole particular organism or individual. The number of cells may be a hundred as in some very small plants and animals, or it may be a thousand, or a hundred thousand, or a million, or billions as in the human body—all through a continuous process of division from the *one original cell*. In this process of cell division, the

chromatin plays a very important rôle. The part the chromatin plays may be summarized in the following description (see Figs. 11 to 17, inclusive).

When a cell gets ready to divide into two cells, the chromatin network disentangles itself until it becomes one long, continuous string or coil. This string then breaks into a number of segments or rods, called "chromosomes." There are two peculiar features about these chromosomes insofar as it concerns our purpose at the present time; namely, their number and their arrangement. First, *the number of such chromosomes is always the same for all members of a given species or group of plants or animals.* Thus, for instance, in the common grasshopper the number is 24, which means that we can examine the cells of any common grasshopper in any part of the world, and we shall always find that the number of chromosomes is 24. *The second noteworthy feature about these chromosomes is that they usually lie in pairs. Thus when, for example, a cell has four chromosomes, one could arrange these into two pairs, the two members of each pair being identical in form and size.* One member of a pair represents the *paternal*, the other member of the pair represents the *maternal* heredity.

As soon as these chromosomes have formed, they arrange themselves into the center of the cell, or as it is usually stated, they move to the equator of the cell. Here each chromosome separates along its longitudinal axis, so that from each chromosome, there are now formed two which are exactly alike. Half of these move toward one end or pole of the cell, while the other half move toward the opposite end or pole. Meanwhile the whole cell has somewhat elongated, a constriction appears along the midline of the cell wall, and finally this constriction becomes complete, and we have two cells from the one, each of the two having again the same number and same kind of chromosomes.

The structure of an individual chromosome is known to be very complex, how complex we can, at the present time, only dimly guess. There is no hope at present for much further progress along this line of research until the physicist discovers a new principle in optics which enables us to obtain much greater magnification than we have now. We know, however, that a chromosome is made up of a great number of small units. Under high magni-

fication many chromosomes appear very much like a string of pearls. Each individual pearl on that chromosomal string having, according to both direct and indirect evidence, some definite relation to one or more traits or characters of the individual, or, as it is usually expressed, *the chromosomes are the carriers or determiners of all hereditary traits or characters.*

INDIVIDUAL TRAITS

Let us recall once more that every organism starts as a cell, the seed or germ cell, and that this cell comes from the previous generation. It is clear, then, that all those characters or traits are inherited (and only those) which are included, some way or other, in the chromosomes which come down in the germ cell from the previous generation. Our original question may now be narrowed down to this form: *Which traits are included in the chromosomes of the germ cell?*

We distinguish for our purpose, two kinds of characters, namely, *racial characters* and *individual characters*.¹⁸ By racial characters are meant those characters always associated with a racial group or a species, which characters are fixed and are therefore, of course, inherited from generation to generation. This means nothing more than that every organism produces its own kind, or, as the adage goes, "like begets like." Roses produce roses, thistles produce thistles, flies produce flies. With these inherited racial peculiarities, the study of heredity does not deal. *Individual characters*, on the other hand, are those peculiarities, which make members or individuals of the same group or species differ among themselves. An example will probably help to make the matter clear. We expect, for instance, a human being to have hair and a pair of eyes: *racial characters*. But whether the hair will be black, or red, or blond; whether it will be straight or curly, thick or thin; whether the eyes will be blue, or gray, or dark—these are the things we wonder about: *individual characters*. *The repetition or nonrepetition of these individual peculiarities in successive generations constitute the problem of biological heredity.* The question, therefore, resolves itself into what individual characters are contained in the chromosomes of the germ cell. Size, that is, whether an offspring is small, medium

size, or large, is one such individual character, determined in the chromosomes, but *how* small, *how much* of medium size, and *how* large is determined by environment in the broadest sense—climate, food, mode of living.

With all that has been said above as a background, we may sketch broadly the question which we shall have to answer in our remaining chapters on this subject:

First, which *normal* individual characters are contained in the chromosomes of the germ cells and what laws govern their repetition or nonrepetition in successive generations?

Second, what abnormal individual characters, such as disease, for instance, or susceptibility to diseases, are contained within the chromosomes, and how are they (if they are) repeated in successive generations? Further, can individual peculiarities, not yet present in the chromosomes, become part of the chromosomes?

Third, what effect or influence should this knowledge have on man in laying out his course through the known waters of the present and the uncharted seas of the future?

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CHAPTER VII

THE MENDELIAN LAWS OF HEREDITY

On the second day of October, 1910, biologists from all countries of the civilized world gathered in the little city of Brünn, in what was then a part of Austria. The occasion of this distinguished gathering was the dedication of a monument to a man whose name had become the byword in the world's biological laboratories during the short span of ten years. Biologists of all schools and creeds marched that morning to the old historical square in front of the Augustinian monastery. Great was the surprise of many of these scientists when the unveiling of the marble monument revealed the full form of a man clad in the humble robe of a Catholic priest, Father Johann Gregor Mendel.

THE STORY OF MENDEL

Born of poor parents on a little farm, young Mendel had to work, from very early years, with his father in the fields and in the little orchard, where an appreciation of nature was to be born. In later years, Mendel liked to recall the pleasure he had enjoyed in those days by improving the quality of the fruit by crossing and grafting. Mendel's parents made great sacrifices to give him an education, then an expensive luxury that only the well-to-do could afford. In spite of the sacrifices the family made, they could not furnish more than half the tuition, and young Mendel had to work at all sorts of things to make up the deficiency. When he was 16, his father, due to a serious injury, was unable to furnish the assistance that had been given up to this time. One of his two sisters sacrificed whatever share might be coming to her as a dowry in order that her brother might finish his education. It is a rather noteworthy coincidence, that, about this same time in France, another great scientist was enabled to receive an education through the same sisterly sacrifice, Louis Pasteur.

After Mendel had completed his college studies, and now being 21 years of age, he joined the order of Augustinian Monks, who



JOHANN GREGOR MENDEL (1822-1884)

Father of the Experimental Method in the Study of Heredity

Many writers cannot understand why the brilliant observations of Mendel attracted so little attention at the time of publication, and the blame is usually laid to the fact that his work appeared in a small local journal. As the *Brünn Journal* was on the regular exchange list of the British Royal Society, however, other reasons must be assigned. Nordenskiöld finds the two prevailing prejudices of the time—prejudices that lay deep—the chief cause. First, that the first real experiments along evolutionary work should have come from a Catholic priest, and secondly, that the whole theory of Natural Selection rested upon the idea of constant variations taking place, whereas Mendel's brilliant experiments denied the very variability upon which the prevailing theory of evolution rested.

Thus Mendel's work would not have been accepted by a single one of the leading scientific journals. In the words of Nordenskiöld, "We have only to remember that Mendel denies the variability in those characters that he observed, whereas all the biologists were just at that time seeking after variations as material in proof of natural selection; and then come these assertions as to the absolutely constant or constantly divisible characters from the pen of a monk in a monastery! It would certainly have been a miracle if they had found support from the generation that had been brought up on Haeckel's *Natural History of Creation*."

devoted their lives to the higher education of Catholic boys and young men.

Shortly after his ordination to the priesthood, he was assigned to the high school of Brunn, where he taught natural science for about 14 years. In 1868 his brother priests elected him Abbot of their monastery, a delicate compliment to his character, kindness of heart, and exemplary life as a priest. He died in 1884 after prolonged suffering from Bright's disease, respected by all, loved by those who knew him, but unrecognized and unheralded in the annals of scientific glory. His far-reaching discovery in the riddle of biology (heredity) lay buried and forgotten on the dusty shelves of a small-town library. His time and contemporaries had only an ear for the evolutionary speculations of Charles Darwin, and not for fundamental laws of nature discovered in a secluded monastery garden by a humble priest.¹⁹

It was during the years of his teaching period that, during his spare hours, Father Mendel conducted in his small monastery garden, those experiments on the breeding and heredity of peas which proved to be veritable building stones for the science of heredity. In planning his epoch-making experiments, Mendel adopted an attitude markedly different from that of earlier workers in his field. Up to his time, the investigators had considered the living object which they were studying as a distinct "whole," and their failure to elucidate any general principle of heredity "was due to their not having concentrated upon particular characters or traced them carefully through a sequence of generations." Organisms produced other organisms more or less like their parents, and that was all there was to it. Mendel's success and his greatness are ascribable to the genius of intellect which caused him to see that the only logical way to approach the problem at hand was to use as the material of his experiments, just those plants having "individual and sharply contrasted characters." The common edible pea was his favorite and most important object of study.²⁰

THE EXPERIMENT OF MENDEL

There are peas which have wrinkled surfaces and some which have smooth surfaces; peas which are yellow in color, and peas

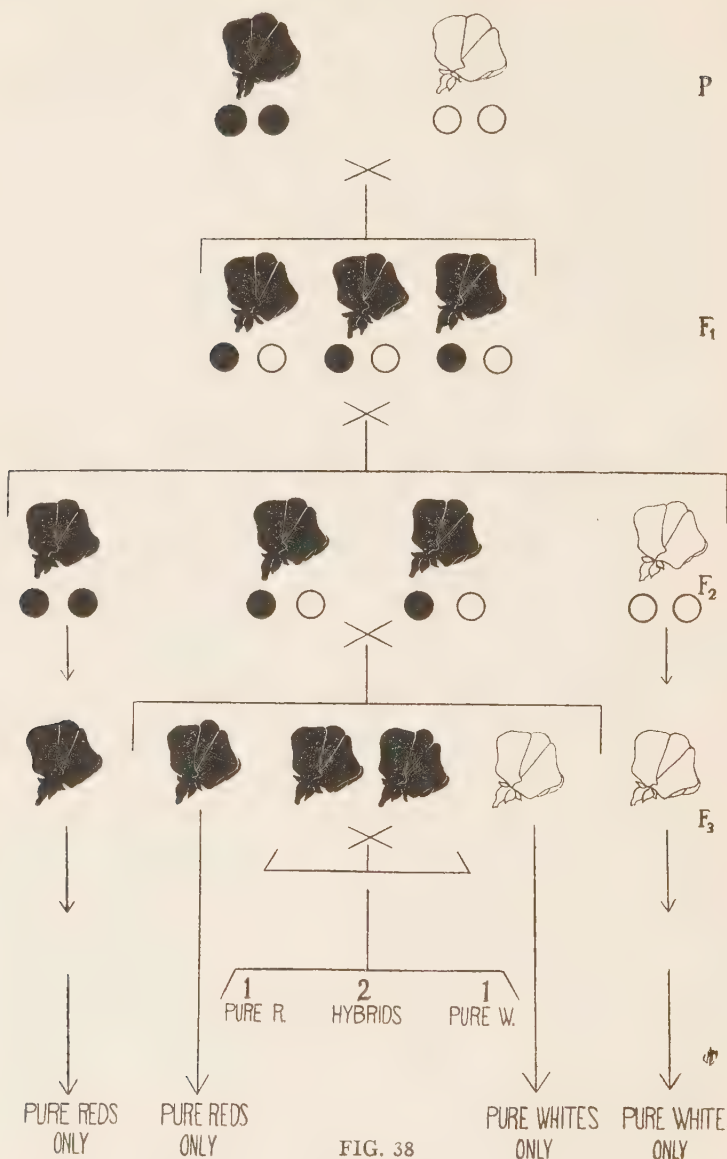


Diagram showing behavior of one Mendelian unit character. Solid black flower represents violet-red variety of pea blossom; white flower represents white variety of pea blossom. P, parental generation; F₁, first filial generation; F₂, second filial generation; F₃, third filial generation.

which are green in color; pea plants with long stalks and pea plants with short stalks. Mendel observed these contrasted characters, crossbred the plants possessing them and watched the results. He was anxious to know just what characters would come forth in successive generations.

From the results and from his masterly interpretation of them, he enunciated the famous laws of heredity which bear his name. To establish his proof, he labored over a period of eight years, examined more than 10,000 plants (which probably means over 100,000 individual peas), traced their ancestry so thoroughly, kept his seeds and tabulated his findings so carefully, and designed the whole plan of experimentation in such detail and foresightedness "that for the first time in the history of studies in heredity, no extraneous or inexplicable data were allowed to enter the problem."²⁰

In considering Mendel's experiments, we are at once struck with the simplicity of his method; a simplicity which will strike us the harder, the more fully we consider its far-reaching results, but a simplicity which always has been the outstanding characteristic of true genius.

The first and simplest of Mendel's experiments is illustrated in Figure 38. You will notice, on the right-hand side of this figure, the symbols P, F₁, F₂, etc. The letter P indicates that the flowers in the first row of the figure represent the "parental generation"; i.e., the experiment begins with these flowers. The symbol F₁ means "first filial generation" and indicates that the flowers in the second row are the offspring of the flowers in the first row. The symbol F₂ stands for "second filial generation" and indicates that the flowers in the third row represent the "grandchildren" of the flowers in the first row. Similarly, the symbol F₃ means "third filial generation" and denotes that the flowers of the fourth row are the "great grandchildren" of the flowers in the first row of the figure. You will further notice the rings below the flowers in the first three rows. These rings indicate the "germ cells" of the flowers. A dark ring represents a germ cell carrying the determiner for violet-red color, while a light ring indicates a germ cell carrying the determiner for white color.

The flowers used in the illustration represent two varieties of pea blossoms. The heavy dark flower stands for the "violet-red" variety, while the light flower represents the "white" variety of the pea blossoms. For simplicity, we shall refer to the first as simply the "red" variety.

MENDEL'S FINDINGS

Color is, therefore, the characteristic on which we are to concentrate our attention. It is essential, however, that at this point, we remember that, before Mendel began his experiments, he did something which others had always failed to do. He made sure that his plants (of the parental generation) were pure in regard to the character under investigation, by cultivating them for three years in the open and in the greenhouse. In addition, Mendel continued to cultivate his plants through all the seven years of the actual experiments, thereby establishing a definite control for his results. After having in this way made sure of the untinged "redness" and "whiteness" of the blossoms, Mendel cross-fertilized them. In the following year, he grew the seeds which he obtained from these in turn only to find that all the offspring (F_1) were completely red in color—the white color of the one parent plant having apparently disappeared. What happened to that white character? Mendel thought that the answer to this question could be found only by continuing the experiment under the strictest control. He, therefore, made sure that no insects or other outside agency would interfere with his plants while they were in a state of flowering. His next step was to breed these plants called "hybrids" (on account of having parents of different varieties). He allowed the hybrids to become self-fertilized.

In the following year for every three red ones there was one single white blossom (see F_2). We know now that, although the hybrid flowers (F_1) may all be red in appearance, some of these really possess the germ of whiteness. The color which shows (in this case red) is called "dominant," and the character which does not show in the hybrids of the first filial generation (in this case the white color) is called the "recessive" character. The question now arises, Why should there be three times as many red flowers as there are white ones? Mendel answered this, not by theorizing,

but by carrying on the experiments until a third filial generation was produced, F_3 .

A group of white flowers appeared. The white parent from which these sprang must have lost not only the red color, but even the germ which carried the red color. Such an organism is therefore called a "pure recessive." This means it never can produce again a red flower unless mated with another red flower. By itself or crossed with others like itself, it can produce only pure white flowers.

A group of red flowers also sprang forth. These flowers produced only red ones in turn, and must therefore have lost the germ which carries the white color. Such organisms are called "pure dominants."

Still another group is to be considered. In this group one finds the ratio of *three* red ones to each white one. However, if we should now breed further we shall see that one red one begets only red flowers. This is, therefore, again a "pure dominant." The white begets only white ones which in turn beget only white ones which are therefore "pure recessives," while the two red ones in the center (which are really hybrids) produce again in the same ratio of three red to one white flower. So you see we must correct any ideas we may have had on the subject. We really have, as subsequent breeding shows, *not three red flowers to one white, but one red, one white, and two hybrids*. So far, we have given only the facts or data which were obtained in the process of the various fertilizations. But facts get their importance only from the meaning they convey to us and from the principles and laws which we are able to formulate. Let us again return to the hybrids which are represented in the second row of Figure 38. "Here the hybrid character," says Mendel, "resembles that of one of the parents so closely that the other either escapes observation completely or cannot be detected with certainty."²⁰ Therefore, when two contrasting characters such as redness and whiteness in color are present in the parents, they do not, as a rule, blend in the offspring, but one is dominant, and appears fully developed, while the other is recessive and temporarily drops out of sight. If for certain reasons the two contrasting characters do blend in the offspring as is really the case in many characters, then all the off-

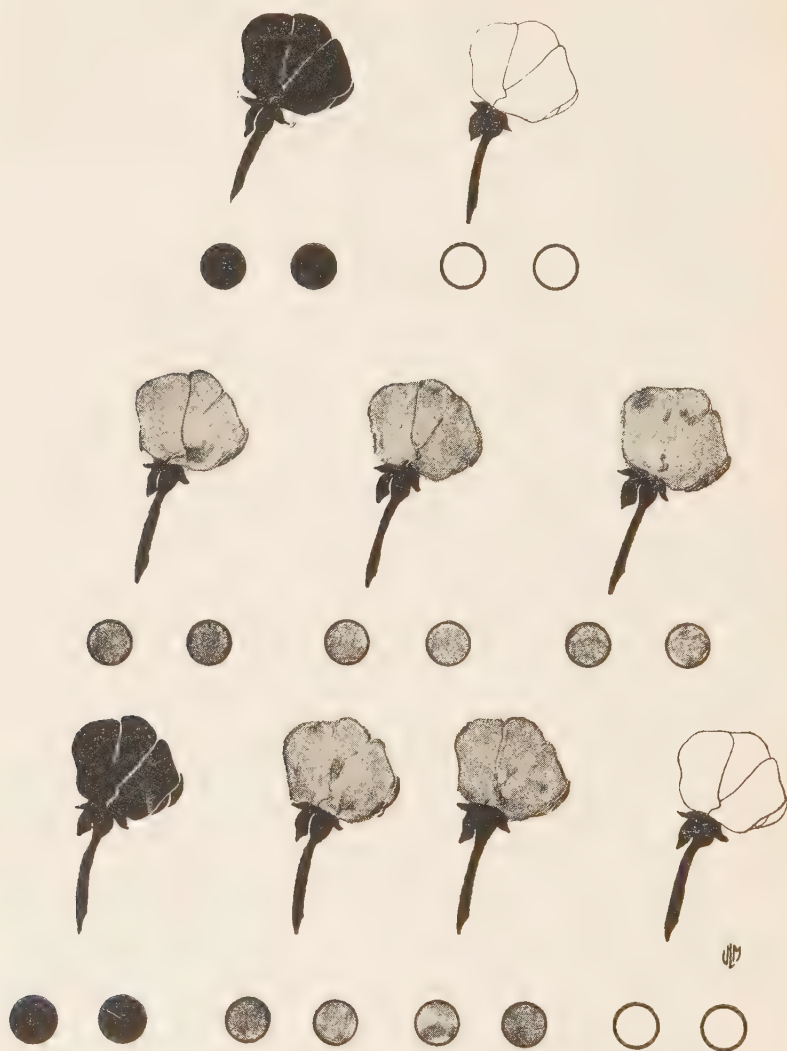


FIG. 39

Diagram showing blending of Mendelian unit characters.

spring are uniformly of that type as is illustrated in Figure 39. Here the parent flowers are also red and white. In the hybrid generation we should, therefore, get either all red flowers or all

white flowers, but we get pinks. But no matter how many flowers we would raise in this generation, they would all be uniform in their color; namely, pink. In the next generation, however, the Mendelian ratio of one "pure dominant" to two "hybrids" to one "pure recessive" appears in unadulterated form. The explanation of such cases of blending is too complicated to attempt here.

THE LAW OF DOMINANCE

Which characteristic of a given series is dominant, can be established only by experiment. We know, for instance, that in most fur-bearing animals, such as guinea pigs, rats, mice, and similar animals, black color dominates over white, smoothness of hair over curliness of hair, shortness of hair over the long angora type of hair, while in many plants, tallness dominates over smallness. In corn, the starchy variety dominates over the sugary variety, in cattle, black dominates over red, so that, for instance, the offspring of a red Polled and a black Angus will be completely black.

To come back to Mendel's explanation of dominance. He assumed that the plant hybrids produce two kinds of germ cells in each sex, two kinds of pollen grains and two kinds of ovules. This is indicated by the rings below the flowers in the F_1 generation of Figure 38. One kind possesses the dominant characteristic derived from the dominant parent (in our case, the red flower), the other kind of germ cell possesses the recessive characteristic derived from the recessive parent (in our case, the white flower). What does this mean? Simply this: that the dominant and the recessive properties of the parents are conveyed to separate germ cells of the hybrid. No single germ cell can carry both dominant and recessive properties of the same character. It is either purely dominant or purely recessive and never partly the one and partly the other. The germ cells themselves are not hybrids, though the individuals that produce them may be. This is what Mendel called the "law of segregation," which is the most important feature of this theory.

How did Mendel explain the ratio of 3 to 1, which is found in the second filial generation? Mendel concluded that not only are both dominant and recessive germ cells produced in the hybrid, but that they are produced in exactly equal numbers. Of four

ovules, two will be dominant and two will be recessive, and of four pollen grains, two will be dominant and two recessive. In this supposition, the fixed proportion of pure and hybrid may be readily explained. Let the capital A represent the dominant characteristic, the small letter *a* the recessive character. These factors which the offspring derives from its parents are transmitted

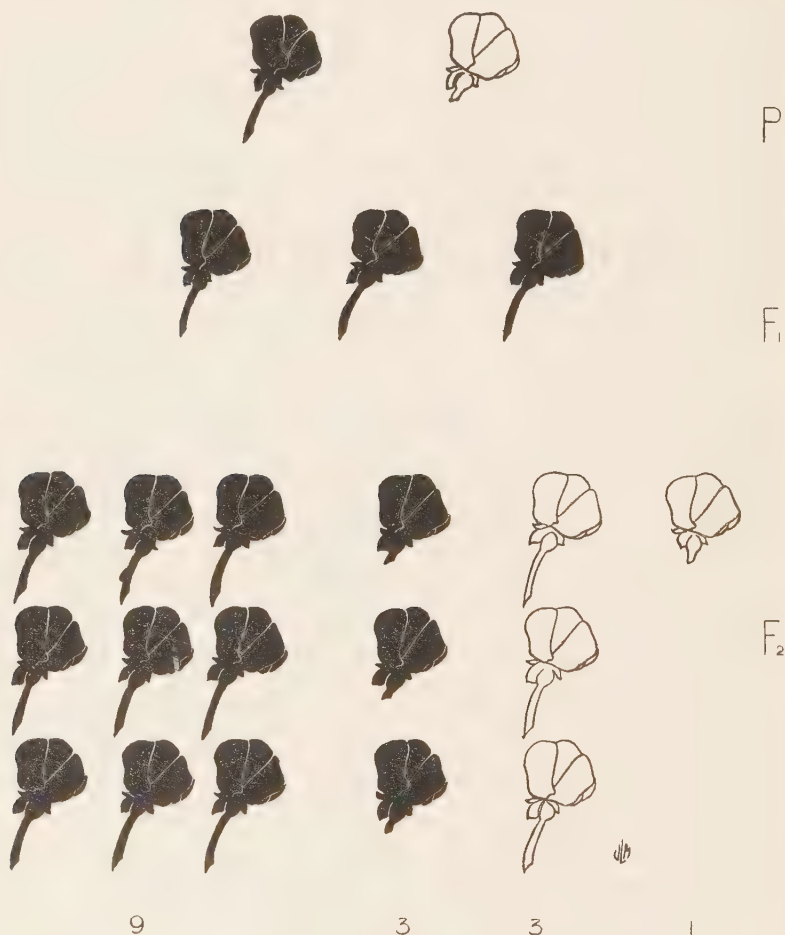


FIG. 40

Diagram showing behavior of two Mendelian unit characters. P, parental generation; F₁, first filial generation; F₂, second filial generation.

through its germ cells in equal abundance. These factors then become segregated so that one half of the germ cells contains only A and the other half contains only a . In the process of fertilization, an A will unite with a as often as with A , and an a will join A as often as a . Thus there will be 2 Aa for each AA and for each aa . Thus we get

$$\left. \begin{array}{l} a + a = \text{Recessive pure} \\ a + A = \text{Dominant Hybrid} \\ A + a = \text{Dominant Hybrid} \\ A + A = \text{Dominant pure} \end{array} \right\} \text{ equals 3 to 1.}$$

To use Mendel's own words: "It is now clear that the hybrids form seeds having one or the other of the two differentiating characteristics and of these, one half again develop a hybrid form, while the other half yields plants which remain constant and receive the dominant or the recessive properties respectively in equal number."²⁰

ALTERNATIVE INHERITANCE

In the experiment just described, plants were used which differed only in one outstanding characteristic; namely, color. Now Mendel wondered whether the laws he had just discovered would apply to each pair of differentiating characteristics when several diverse characters are united in the hybrid by a crossing of parents who differ in more than one outstanding property. In Figure 40, an experiment is reproduced where the two parents differ in two characters; namely, color and size. The one parent flower is red and tall, the other is white and short. The first filial generation or the hybrids are all red and tall, therefore in appearance completely like the one parent. By allowing these to be fertilized, their offspring again produce the same ratio, namely:

9 tall red ones;
3 short red ones;
3 tall white ones;
1 short white one.

There is here again no blending and the ratio of tall to short is 12:4, that is 3:1. Regarding color, a similar ratio of reds to white appear; namely, 12:4 like 3:1. From this experiment, as well as

from other more complicated ones, Mendel formulated the principle that "the offspring of the hybrids in which several essentially different characteristics are combined, exhibit the terms of a series of combinations, in which the developmental series for each pair of differentiating characteristics are united. Furthermore, that the relation of each pair of different characteristics in a hybrid union is independent of the other differences in the original parental stocks."²⁰ By trying all possible combinations in such offspring, the demonstration of which is too complicated to attempt here, he further established the principle "that the constant characteristics which appear in the several varieties of a group of plants, may be obtained in all the associations which are possible according to the mathematical laws of combination, by means of artificial fertilization."²⁰ The last principle is, as you may readily conceive, of immense practical value to the agriculturist and stock-breeder especially.

It may be well to summarize the Mendelian Principles of "Alternative Inheritance" or "Hereditary Splitting" here. These three principles are:

THE PRINCIPLE OF DOMINANCE. Whenever there are contrasting unit characters present in the parent, such characters do not, as a rule, blend in the offspring. One is dominant and usually appears fully developed, while the other is recessive and temporarily drops out of sight. Where there is blending, all the offspring of a hybrid generation are, nevertheless, uniform.

THE PRINCIPLE OF UNIT CHARACTERS. The total heritage of an organism may be analyzed into a number of characters which are inherited as a whole, and are not divisible into any smaller units. These are the so-called "unit characters."

THE PRINCIPLE OF SEGREGATION. Every individual germ cell is "pure" with respect to a given unit character, even though it came from an "impure" or hybrid parent. In the germ cell of a hybrid, there is a separation of the determiners of contrasting characters, so that different kinds of germ cells are produced, each of which is pure with regard to any given unit character. Such separation forms the basis of the principle of segregation of unit characters, or of the purity of germ cells. Every individual is a double being, double in each cell, one half having been derived from the male

and the other half from the female cell. This double being or "zygote," again becomes single in the formation of the germ, only to become once more double when the germ cells unite in fertilization. Purity of type thus acquires a precise meaning. It is dependent on *gametic segregation*. It depends on the meeting of two gametes bearing similar factors and when two similarly constituted gametes do thus meet in fertilization, the product of their union is pure. The belief so long prevalent that purity of type depends essentially on continued selection, is thus shown to have no physiological foundation. Similarly, it is evident that an individual may be pure in respect to one character and crossbred or "impure" in respect of others.

APPLICATION OF MENDEL'S LAWS

It should not be difficult to realize the immense practical value such discoveries have from the economical standpoint. Indeed, the results obtained during the past twenty years surpass the most optimistic hopes Mendel himself may have had. Agriculturists have improved many a product by its application. Breeders of animals have bettered their stock. A few examples suffice to impress what really needs no proof.

The blue Andalusian fowl is a very desirable variety. Breeders had long recognized the futility of obtaining a pure breed of these birds. No matter how carefully the blues were selected, they always threw wasters of two sorts, some pure black and others a peculiar white with black splashes. Careful breeding by Dr. Punnet, professor of biology at Cambridge University, England, showed that on an average, one half of the offspring from a pair of blue Andalusians were *blue*, one quarter *black*, and the other quarter *white*. These numbers at once suggested to him the Mendelian proportions of one dominant, one recessive, and two hybrids. He thereupon concluded that the blue Andalusians were themselves hybrids, while the black and white birds were the pure types. So he crossed black with whites with the result that the offspring were all blue. This was in accordance with Mendelian proportions. Therefore, instead of considering the black and white offspring outcasts as former breeders had done, modern breeders mate them now—a saving of considerable value.

A still more interesting example of the practical application of Mendelian principles is afforded by the experiments which Professor Biffen carried out in Cambridge on English wheat. Taken as a whole, English wheats compare favorably with foreign ones in respect to their yield. On the other hand, they have one serious defect, in that they are liable to suffer from the attacks of a rust fungus. There are many other wheats outside of England, especially in America, which are small eared, therefore possessing less yield than the English, but which are immune to rust. Professor Biffen crossed the "English large, but susceptible to rust" wheat with the "American small, but immune to rust" variety. He thus had four characteristics with which to work: *largeness against smallness*; *susceptibility to rust against immunity to rust*. The ideal combination therefore, would be to combine in one wheat the English largeness and the American immunity to rust. The offspring of the first generation, however, were all large and susceptible to rust. Therefore *largeness* and *susceptibility* are dominant characters. What does this mean? Simply this: that when he cross-fertilized these tall, susceptible hybrids he obtained:

9 LR 3 SR 3 LI 1 SI

The three large immune plants will breed true. So that Professor Biffen has transferred the immunity of the small American wheat to the large British variety. This wheat has already been shown to keep its qualities unchanged for several years, and the intelligent application of Mendel's principles will save the English farmers an annual loss of four hundred million dollars.

Go to any exhibition of products; visit any of the stock expositions at any county or state fair; go to the breeder of pure lines of fancy horses, dogs, or other animals! All improvements in these fields are practically built on Mendel's work. The farmer or breeder might not know it; he might not even have heard of Mendel, but it is to Mendel that he owes his success.

You may ask what normal individual characters follow the Mendelian laws of heredity. A complete answer to that question can be obtained only through experimental work, and not through statistical compilations. At the present time it is, however, safe to say that, in all probability, all those characters are Mendelian in their behavior which have any relation to sex, form, size,

shape, and appearance (such as coloration) of the structural parts of an organism. Little has as yet been done in the way of throwing light on the more important functional characters, especially of the higher types of life.

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CHAPTER VIII

THE GERM PLASM, DISEASES, AND ACQUIRED CHARACTERS

THE GERM PLASM. In discussing the topics of germ plasm, diseases, and acquired characters, we must remember that these can be discussed intelligently only in the light of what we have thus far learned of heredity. The problem under consideration is this: Can and does disease affect the chromosomes or any other parts of the germ cells which may have something to do with the repetition of individual traits from generation to generation? And similarly, can and do characters or peculiarities which have been acquired permanently by the body or any part of the body during the lifetime of an individual, affect the germ cells of that particular individual in such a way that these same characters are repeated in the succeeding generations? To appreciate fully the significance of these questions, we must know a little more about the architecture of the germ cell than we have learned up to the present time.

Therefore let us make a careful study of some germ cell with which we are somewhat familiar; namely, the egg of a hen.

A TYPICAL GERM CELL. In spite of its enormous size the hen's egg is only a single cell in the true sense of the word. However, not all of that egg is "germ plasm" in the hereditary sense of the term. In Figure 41, A, are shown in diagrammatic form, all the parts of such an egg. Note the outside heavy line which corresponds to the hard, porous or calcareous shell, the one that we break and shell off before eating the egg. Immediately below this outside shell, there are two more coverings or membranes, which can be seen very easily when peeling a hard-boiled egg. At the blunt end of the egg, there is a space between two membranes filled with air for the growing embryo. Below the inner of these two membranes, there is a large amount of albumen or white of egg which serves as food. In the center of this albumen you will

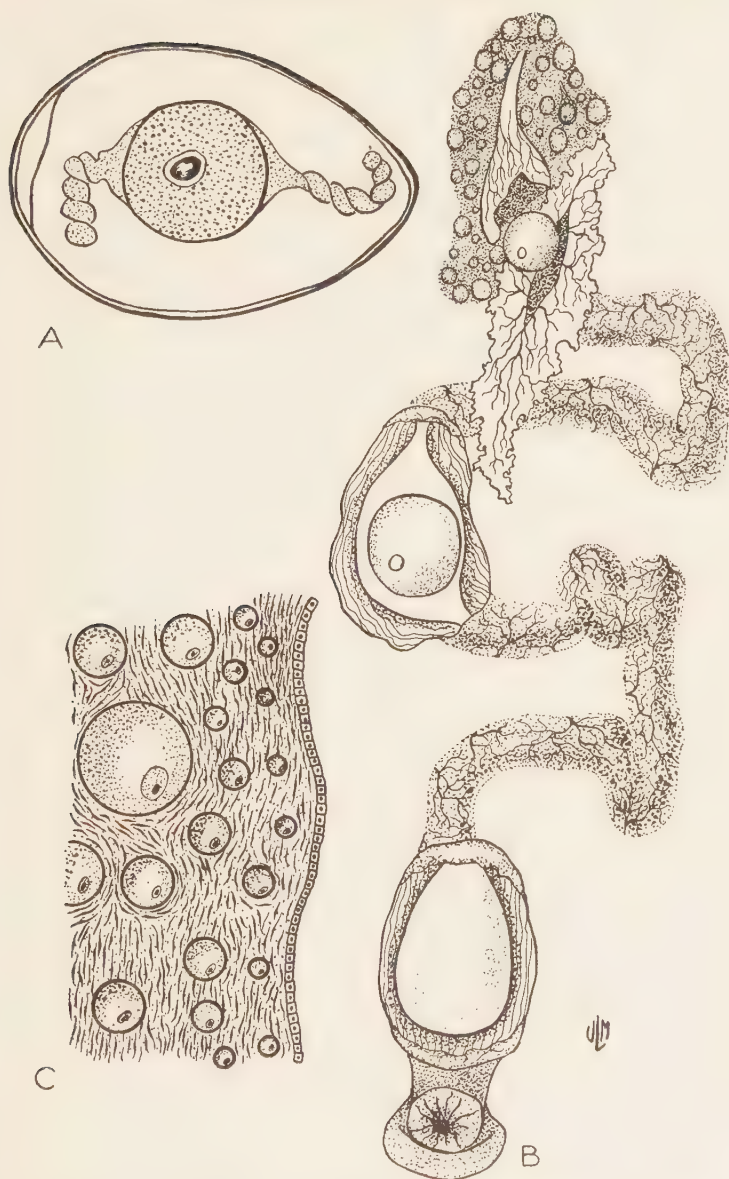


FIG. 41

Reproductive organs of hen. A, diagrammatic section of egg; B, ovary and oviduct showing passage of egg, C, diagrammatic cross section of small portion of ovary of young chick (B after Duval).

notice a spherical body. Observe this part well. First note that it is surrounded or enveloped by a membrane, the vitelline membrane, which corresponds to the cell wall of an ordinary cell. It is filled with a yellowish material called "yolk," arranged in concentric layers, a substance which, for our purpose, we may think of as corresponding to the cytoplasm of an ordinary cell, although it serves as food. In the center of this yolk and on top of it, you find a very small body, the "nucleus." Remember that the chromosomes are an actual part of the nucleus and that these same chromosomes are the carriers of heredity. In them are contained the traits and characters which make up an individual.

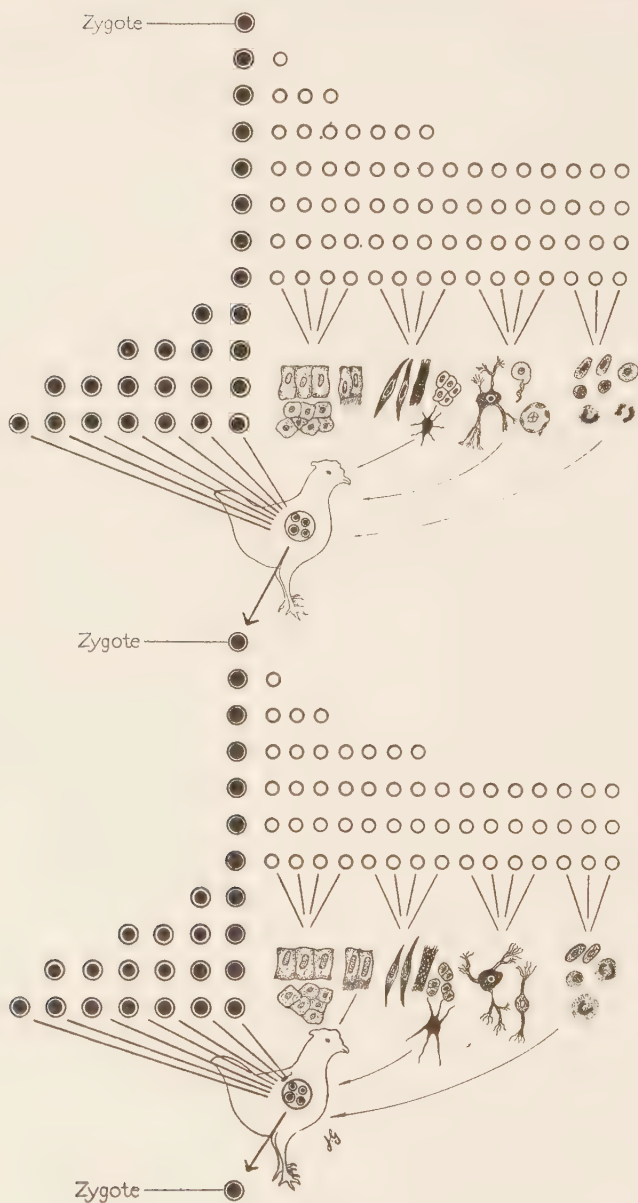
By studying Figure 41, B, the matter will be made still clearer. This figure represents the ovary and oviduct of a hen. The ovary is the organ in which the egg cell is originally developed, and the oviduct is the tube through which the egg reaches the outside world. Note what parts of the egg are formed within the ovary: the vitelline membrane, yolk, and the nucleus. Note that all the other parts are added to the egg cell proper while it travels down the tube or oviduct, such as the albumen, the two inner membranes, and the hard porous shell. The last-named parts (those which are added to the egg cell on its way down the oviduct) are of no importance for our present purpose because they are present only in certain forms of life, and not in all. The parts which are present in the egg as it leaves the ovary are found in the egg cells of all forms of life, and so we must try to learn their significance. Figure 41, C, shows an enlarged view of a small portion of the ovary of a newly hatched chick. *The remarkable thing that strikes the observer immediately, is that already, at this early moment, all the egg cells which that chick can ever have, and therefore all the eggs it can ever lay, are already present. No matter how well one may feed poultry, no matter in what sanitary surroundings one keeps them, no eggs are added.* This, however, does not mean that one cannot influence the egg-laying capacity of the hen.

WHICH WAS FIRST, THE EGG OR THE CHICKEN? The fact that all the possible egg cells are already present when the chick begins its independent life, is food for thought. The old joke regarding which came first, the hen or the egg, now becomes a real

scientific question. In fact, this very question has caused a great deal of discussion in biological circles. Let us see what such a question implies. If the egg comes from the hen, or, to put it more clearly, if the hen makes the egg cell, and the egg cell contains in its chromosomes that which is transmitted to the next generation (which is heredity), then it stands to reason that the individual of each previous generation would make the heredity of the succeeding generation. Now, everything an individual does bears the stamp of the external conditions in which the work was done, and is, in fact, more or less influenced by those conditions. To understand this, one has but to recall that there are certainly eggs poor in food quality, and eggs rich in food quality. The reason for this is because some hens live in good environment and are fed better food than others.

Suppose we incubate 24 female-producing eggs coming from the same two parents. After the 24 chicks have hatched out, we immediately place each in a different environment, and also feed each a different diet. In our supposition, these 24 hens, though coming from the same parents, would, in their turn, produce egg cells quite different not only from each other, but also different from the egg cells of their parents. We know, however, that such is not the case. If you will examine Figure 41, C, you will note that the egg cells are not all of the same size, some of them being considerably smaller than others. These egg cells are in the process of growth, but the growth is only in the yolk material, not in that part which, later on (in the finished egg) develops into the body of a new chick; namely, the nucleus with its chromosomes. The nucleus, and you will recall that it is this part which is responsible for the repetition of individual characters, is already present and quite alike in all these eggs, no matter what their size may be. Where, then, does this part of the egg cell come from? Not from the chick proper, but from the previous egg cell.

In other words, we have the answer for our timeworn joke: *The egg does not come from the hen, but from the egg.* The germ cell forms not only the body of the individual, but also, directly, the germ cells in that new body. The body of the individual has nothing to do with the making of the germ cells, these come from a previous germ cell in a direct line through a continuous process of



division. *The original fertilized germ cell does two jobs at the same time; namely, it develops at one and the same time the body of the animal in one direction, and the germ cells of that body in another direction, so that when the body is formed, the germ cells for the next generation are also formed.* This is illustrated in Figure 42.

In the upper row of this diagram, we see the fertilized egg cell, which, as you will recall, contains a set of chromosomes, coming in equal numbers from the paternal germ cell and the maternal germ cell. You will also recall that the new individual is formed from this one cell through a continuous, uninterrupted process of division. Now study carefully the first division shown in the second row. Observe that there is a difference in the two resulting cells. By following down the succeeding divisions you will note that there is being established a line of cells on one side which are exact replicas of the original germ cell. In all the other cells a marked change in the succeeding division is taking place, the cells becoming more and more differentiated into the various kinds of cells which make up the adult body of the organism. Some of these differentiate into long, slender muscle cells, others into closely compact bone cells, others into long nerve cells with many processes, and still others into the various kinds of epithelial cells. But the germ cells do not differentiate at all during the continuous process of division, they multiply themselves without any change. And the reason is obvious. Why should they differentiate, since their function remains the same as the function of the original germ cell? They are to be germ cells in their turn, and perform the same functions as their forbears; that is, they are to begin a new generation as in the lower part of the diagram. Now, since the establishment of this germ-cell tract goes on at the same time that the formation of the body goes on, we can understand how, at the time of hatching in the chick, or at the time of birth in mammals, all the egg cells such animals will ever have during their lifetime, are already there. It further shows how the germ cells of an individual are not made by the body cells of that individual, but they come into being directly from the very germ cells from which that individual possessing them comes into being.

CONTINUITY OF THE GERM PLASM. This separation of germ cells and body cells is known in biology as the theory of the *continuity of the germ plasm*. You may say, yes, that sounds interesting, but has anybody ever seen it taking place? That should be a legitimate question, especially since the biologist is supposed to arrive at his conclusions and build up his theories on carefully observed facts. Early origin of special germ cells, in the sense just outlined, has been observed in several species of worms, in a few species of *crustaceans*, in quite a few types of insects and spiders, while indications of the same early separation are not missing in a number of other organisms. In view of these observations and other considerations, it seems justifiable to say that the distinctness of the germ cells on one side and the body cells on the other should be considered more than a mere hypothesis, although a few recent investigators believe they have discovered evidence against such a distinctness of germ and body cells in higher forms.

ACQUIRED CHARACTERS

With the origin of the germ cells thus established, we are in a position to ask the all-important question: What relation have the germ cells to the parental body which, though not making them, nevertheless bears them and from which they are eventually liberated to form a new generation? In the treatment of this question, there is great need for clearness of thought.

First, let us bring out what the question does not imply. An example may help. Suppose we subject our favorite laboratory animals—mice, rats, or guinea pigs—to repeated, strong doses of alcohol until we notice a decided injurious effect in them. After such extended treatment, if they should give birth to offspring, such offspring will show that they suffer from the same injurious alcoholic effects as did their parents. Is this part of our present question? No. Why? Because, while poisoning the bodies of the parent animals, we have, at the same time, poisoned directly the germ cells. The germ cells did not become affected because of or through the body cells, but the alcohol reached the germ cells directly, independently of the body cells. In other words, both body cells and germ cells happened to be subjected to the harmful environment at the same time. Such effect on the germ cells may be

accomplished with almost any slow, saturating poison, but it is clearly a matter of environment, not of heredity. This may seem to you like hairsplitting, but it is quite necessary to keep the thought of environmental influence decidedly separate from that of actual hereditary influence, if we are to understand modern biological discussions. If we remove the injurious environment from the offspring, if we no longer submit the offspring to the effects of alcohol poisoning, the offspring will soon improve, especially if placed under good and appropriate environment and treatment. Such cases of direct influence on the germ cells are not part of the heredity problem of the biologist, though they are of vast importance from the sociological and medical point of view. Let us repeat, then, that we are *not* asking ourselves at the present time: Is it possible to influence the germ cells in the body of the parent in a direct way? Suffice it to say that it is possible, though often difficult. To this category belong also so-called transmissions of infectious diseases from parent to offspring, of which more will be said later.

WHEN DO PERMANENT MODIFICATIONS OCCUR? The question at issue just now is this: When the body, or any part of the body of the parent acquires a permanent modification through environmental or functional influences, is such a modification transmitted to the germ cells as a permanent modification? Suppose that a young American goes to tropical South America, living there under the hot sun for twenty or thirty years. The hot sun, as the environment in this case, produces a marked change in the complexion of his skin, it becomes tanned. The American in question, after the twenty or thirty years, comes back to this northern climate. His skin will not return to its original fair complexion, the tanned modification will remain with him until his death. This is an acquired character or somatic modification. The question now is: Will this permanent modification of his skin cells transmit the acquired modification to his germ cells so that his offspring, though born in a northern climate—therefore away from the cause of the modification—be born with a tanned skin instead of the normal fair complexion of the northern environment? This is the much-discussed problem of the inheritance or noninheritance of acquired characters—one of the most widely discussed

questions in biology since the days of Lamarck. And this for two reasons: First, because it is intimately connected with the theory of organic evolution; and, secondly, because it is of immense practical consequence.

As to the first reason, biologists cannot conceive how any kind of organic evolution could have taken place unless there were such things as inheritance of acquired characters. Thus Herbert Spencer says tersely: "Close contemplation of the facts impresses me more strongly than ever with the two alternatives: either there has been inheritance of acquired characters, or there has been no evolution."²¹ And Haeckel, the fallen angel among evolutionists, cries out in utter despair, "Belief in the inheritance of acquired characters is a necessary axiom of the monistic creed," and rather than agree with Weismann in denying the inheritance of acquired characters, "it would be better to accept a mysterious creation of all the species as described in the Mosaic account."²² Well, maybe such acceptance would be better, but that is neither here nor there! What we are interested in is simply what our present-day knowledge has brought forth as proof for or against the case of the possibility of inheritance of acquired characters.

The practical importance of the question is obvious. Take as an example the breeding of race horses. If through early and long training, a horse develops the muscles which make for speed, it acquires bodily modifications which will be permanent to itself, that is, the change in these muscles persists, though the horse may race no longer. But, if that bodily modification would modify the germ cells of that horse in the same particular direction, then its offspring would be born with the ability to run faster than its parent. Breeding of race horses would become easier and more successful with every generation. Many useful and harmful modifications could thus be acquired, especially during the plastic period of youth. If these could be transmitted to the next generation and a superspecies produced, the problem of training would be a much simpler one, for each succeeding generation would begin where the previous one left off.

ARE ACQUIRED CHARACTERISTICS INHERITED? *What are the facts in the case? Is there any biological proof that acquired characters are inherited? There is but one answer possible in the light of our*

present knowledge, and that is NO. Thousands upon thousands of experiments have been performed by biologists, most of whom were and still are biased in favor of the affirmative to start with, but the results have all been negative.

To cite some of the experiments. Weismann was one of the first biologists to really question the inheritance of acquired characters. He cut off the tails of mice for nineteen successive generations. Similar mutilations were performed by many other experimenters, but in no case was any inherited result observed. These experiments were really unnecessary, for among many races, bodily modifications of a similar nature have been performed for thousands of years, and no inherited result can be observed up to the present time.

Professor Naegeli brought various plants from the Alps to the botanical garden of Munich. The environment of the two places is, of course, vastly different. Many of the plants during the first year became so much changed that they were hardly recognizable as the same species, and their descendants were likewise quite different from their Alpine ancestors. Here, then, was a case where environment had caused a great change or modification which became not only permanent in the bodies of those plants, but apparently also permanent in the germ cells of these plants, as shown in the next generation. Some of these modifications were observed in as many as thirteen successive generations. There was no doubt as to the reappearance of the acquired characters, but it was not thereby proved that the reappearance was due to the persistence of the novel conditions of the environment which were reimpresed on every succeeding generation, for when these plants were removed after those many years to their original Alpine environment, the acquired characters disappeared. The plants went back to their original Alpine appearance.

Let us note a much more complicated and subtle experiment. Guyer and Smith, of the University of Wisconsin, injected a peculiar lens-destroying serum into female pregnant rabbits, their offspring were born with defective eye lenses whose offspring in turn had defective eye lenses. Does not such an experiment prove the opposite view? By no means! For the serum, injected into the pregnant mother rabbits, affected at the same time the de-

veloping embryos in utero. If a solution is strong enough to dissolve an adult eye lens, then it certainly is powerful enough to destroy whatever is to become eye lens in the embryo! But the third generation, and several generations afterward, showed eye defects of the same nature at birth. Is this a case of inherited acquired characters? No. Because each generation produces in its blood serum antibodies which, in turn, affect the germ cells directly.

Many experiments along this path transgress the ethical limits of scientific inquiry and, besides, they are not even to the point, since they are performed under conditions so utterly different from those ever operating in nature that there is no comparison possible.

KAMMERER'S EXPERIMENT. In this connection, it might be profitable to relate an incident that was published in the October, 1926, issue of *Time*, under the heading of "Cruel Trick."

"There came to light last week a letter revealing one of the cruelest tricks one civilized being could well play on another. It was a letter left by the late Professor Paul Kammerer, famed biologist, who ascended a small hill near Vienna last month and shot himself. For a year, the scientific world had reverberated with Professor Kammerer's report, that, by experiment upon frogs, he had proved to his immensely critical satisfaction that acquired characteristics, such as loss of an arm, blotches on the skin, could be passed from one generation to another. It was contrary to all previous observations on the transference of physical characteristics, and Professor Kammerer was hailed by some as a brilliant genius, by others as a deluded fool. Dr. G. K. Noble of the American Museum of Natural History examined Professor Kammerer's depositions and in an article for *Nature* (British monthly) drew the lenient conclusion that someone may have tampered with Dr. Kammerer's specimens. In particular, certain dark spots on some of the frogs might have been produced, not by inheritance, but by injecting a dark fluid under the skin, perhaps India ink. When he saw this suggestion, Dr. Kammerer, who had lately been offered charge of a new government laboratory in Russia and whose suicide was to be a shock and a mystery to many scientists that had long held him in high esteem, investigated at once.

"All the facts are true," said Dr. Kammerer's last letter, referring to Dr. Noble's articles. Assistants, perhaps malicious, perhaps longing to see their master pleased, had tampered with the frogs. "The work of my whole life has been destroyed."

DISEASES

We come now to the last part of our present problem: Are *diseases* inherited? The problem arising here is not essentially different from the one already discussed. We are again obliged to deal with the old questions of (1) what is constitutionally within the germ? That is, is the determiner for any disease known to be part of the chromatin material of the nucleus in the germ cell; (2) what is acquired by the body; and (3) whether the diseased condition acquired by the body is inherited, or, which is the same thing, whether the diseased condition is transferred in such a way to the germ cells as to be repeated in the succeeding generations.

STRUCTURAL PATHOLOGICAL PECULIARITIES. There are certain pathological peculiarities which have undoubtedly a seat in one or the other chromosome of the germ cells. We say peculiarities, because we usually do not include them under the general term of disease. The best-known structural peculiarities running in some human families are:

Polydactylism, in which more than the normal number of fingers or toes are present.

Syndactylism, a condition in which the fingers or toes are joined together by a sort of web.

Brachydactylism, in which some of the fingers are short and stumpy and contain usually less than the normal number of joints. These people can never find gloves to fit their hands.

FUNCTIONAL ABNORMALITIES. Again it is well to remember that studies in this type of abnormalities are purely statistical studies, and by no means true biological investigations.

The best-known functional abnormalities in certain human families are: (1) Color-blindness, the most common of which is the inability to distinguish between red and green; and (2) hemophilia, or bleeding, which has already been mentioned. It is not such a terrible affliction to be color-blind, though it is a nuisance in these days of red and green traffic lights. Hemophilia is, on the

other hand, a very serious condition. How these abnormalities are contained in the germ cells is not known, although we know that they are contained in that particular chromosome which determines sex. A study of Figure 43 will serve to show why hemophilia runs so peculiarly in these families, and also will serve to show us what really must be the case in order that a disease may be inherited.

It will be recalled that, in an earlier chapter, mention was made of the so-called X chromosome which bears a definite relationship to the development of sex. In the human family, the "odd" X chromosome is present in the male, the female having, in all probability, 48 chromosomes and the male 47. In Figure 43, we start with the assumption that the determiner of hemophilia in the father is contained in his X chromosome, which, for that reason, is represented in heavy black. The father is married to a non-hemophilic woman whose paired X chromosomes are by supposition free from the determiner for spontaneous bleeding, and, for this reason, are represented in light lines. Their son (all sons, of course) receives his X chromosome from the mother, hence he is neither a bleeder nor does he carry the determiner of the disease. The daughter on the other hand, receives one of her two X chromosomes from the hemophilic father. She carries, therefore, the determiner of the disease, although, curiously enough, she is not a bleeder herself. (Fig. 43, B). Now we marry this daughter to a son of nonhemophilic parents. The offspring of this union are, with regard to hemophilia, as follows (Fig. 43, C): One half of the sons are actual bleeders, the other half are altogether free from the affliction. Similarly, half of the daughters are altogether free from hemophilia, while the other half of the daughters carry the determiner of the disease and will transmit it to their daughters in turn again.

TYPES OF DISEASES. Diseases, in the proper sense of the word, may, for our purpose, be classified into two groups; first, diseases caused by outside agencies, such as bacteria and other plant or animal parasites or poisons, and second, diseases which are not caused by outside agencies.

EXOGENOUS DISEASES. A disease of the first group, such as tuberculosis, the different kinds of colds, gripes, and flues, smallpox,

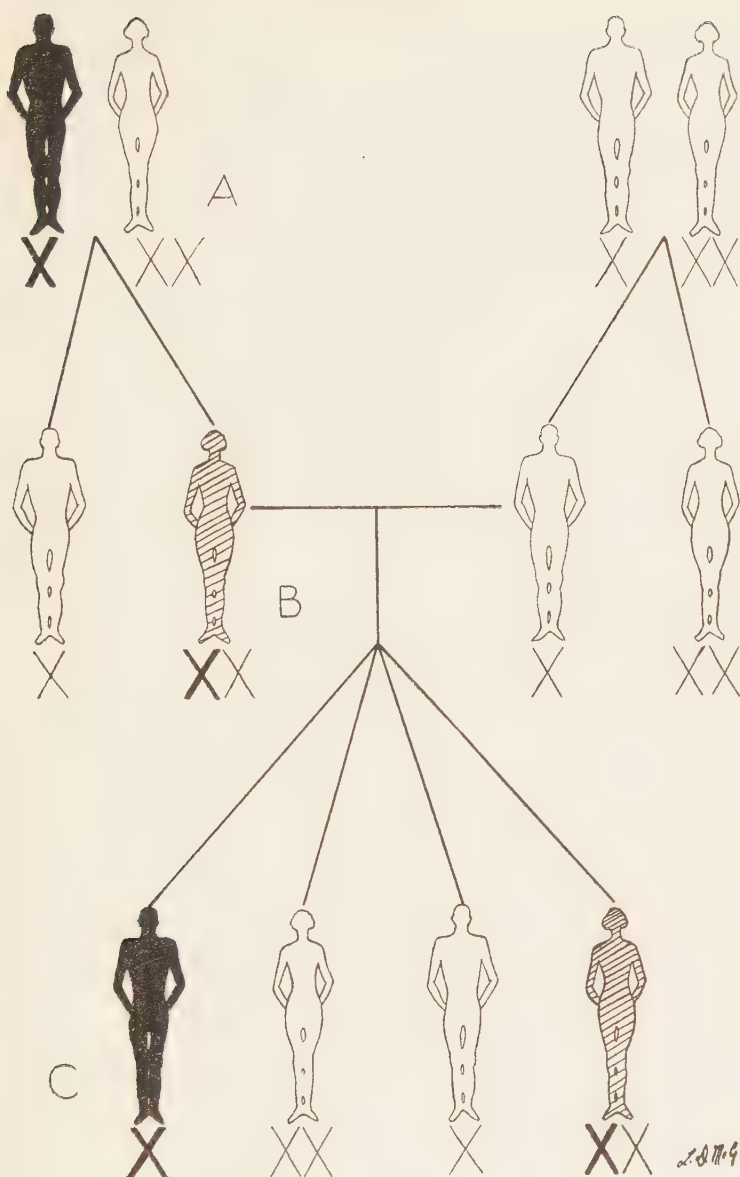


FIG. 43

Diagram showing heredity of hemophilia through X Chromosome. Solid black figures are actual bleeders; the shaded figures represent "carriers" who are not bleeders themselves; white figures represent persons who are neither affected nor are carriers of the disease. A, parents; B, children; C, grandchildren.

typhoid, diphtheria, syphilis, etc., are evidently acquired conditions of the body. The germs, parasites, or poisons, enter different parts of the body, and by their presence and activity create an unfavorable environment for the body. Such diseases are not inherited any more than other acquired characters, no matter how often they show up in a given family. The cause for that repetition, or as the practitioner would say, "run" in the family, must be looked for elsewhere. Especially is this true in the case of germinal diseases, like tuberculosis. The germs of these diseases cannot conceivably become an integral part of the germ cells, and there are no authentic cases on record that they do invade the germ cells. Of course, sometimes children are born with tuberculosis, though very seldom, but then it is a case of prenatal infection, the developing child having been exposed to the same damaging environment as the tubercular mother. From the biological point of view, and in such matters it is the biological point of view which is the only correct one, anything that happens to the embryo after the two germ cells have united to start the new organic life, is acquired, and not inherited.

In many diseases the germs liberate a vast amount of poison into the body of the individual, saturating, as it were, the whole system, including the germ cells. Now, as such toxic poisons lower the vitality of the body cells, so will they lower, though in a lesser degree, the vitality and resistance of these germ cells. Such germ cells, after becoming fertilized, give the new organism a decidedly poor start, the embryo is taken at a disadvantage at the very threshold of life, and it is but natural and to be expected that the resulting individual will succumb much more readily to the renewed attacks of its old enemy in later life. This is the explanation for those cases where acquired diseases run in families. It will be seen that here we have no case of biological heredity but examples of environment; namely, environment of the germ cells or of the embryo.

This may seem a very fine and minute distinction, but it is a fundamental distinction. If such diseases were hereditary in the true sense of the word, we would indeed have cause for despair. But as long as they are due to environment, though the environment may act with the inexorable sureness of heredity, we have

reason to be thankful and hopeful. The reason for our hope lies in the advancement of therapeutics and preventive medicine. For by this advance we shall be able to defend ourselves with increasing success against the attack of such enemies.

ENDOGENOUS DISEASES. Not so easy is the question when we inquire into the inheritance or noninheritance of the diseases of the second group; namely, those which do not have an outside agent as their cause. Examples to the point are diabetes and the various forms of cancerous growths. These and similar diseases are said to be "endogenous," because they have their foundation in the very cells of the body. Such diseases seem to lurk in their hiding places until an appropriate stimulus starts them on their savage march of destruction and death. *They* seem to lurk in their hiding places; *they* need a stimulus! But who are *they*? The diseases? Impossible! Because a disease is not an entity nor a character, but a process, which is initiated by an external cause. Can a process be inherited? Has anybody ever heard of diabetes of the germ cells, or of cancer of the germ cells, or of asthma of the germ cells? Yet that would be necessary in order that these diseases could be inherited. Cancerous growths are rare in young people, unheard of in children, inconceivable in germ cells. And still, we know that these diseases have an iron grip on certain families, while in other families, they seem to be unable to get a start. What then is the solution?

SUSCEPTIBILITY TO DISEASES. The answer is somewhat disappointing in its vagueness, but it is the only answer we can give at the present time in accordance with the known facts. What is really present in these families is a *predisposition* or *susceptibility* to these diseases. But what is this predisposition or susceptibility? We do not know, except that it is the other side of *immunity*. Just as some people are naturally immune to certain diseases, so other people are susceptible to these same diseases. This is best illustrated in the case of cancer, the heredity of which has of late been much discussed and studied.

Dr. Maude Slye, of the University of Chicago, has done and is still doing some remarkable work along this line. Overcoming in a heroic manner the proverbial dislike of her sex for rats and mice, she has, with infinite patience, raised over 50,000 mice

under the strictest control. Mice develop all the various types of cancers and tumors which are found in man. By careful breeding she has been able to obtain three lines of mice which are subject to almost any kind of cancerous growth and every kind of immunity from that growth: (1), strains in which all members develop the specific cancer under investigation; (2), strains in which no cancer at all develops; and (3), strains with a low percentage of cancer. A careful analysis of the figures shows the Mendelian ratio of 1 : 2 : 1. This means that cancerous growths behave like Mendelian unit characters. But in what sense? *In the sense of immunity and susceptibility*. Immunity to cancerous growths and susceptibility to cancerous growths are the contrasting unit characters. Her work, performed under the strictest control, shows beyond reasonable doubt that in mice *immunity* to cancer is the Mendelian *dominant* character, and *susceptibility* to cancer behaves like the Mendelian *recessive* character. From all evidence, it seems scientifically correct to conclude that the same is true of human cancerous growths. Just what this immunity and susceptibility consists of, we do not know, but it is real, nevertheless, as in the case of an earlier English wheat experiment mentioned in Chapter VII. The large English wheat is susceptible to the rust disease, the American small wheat is immune to the rust disease. We may not know why, but this susceptibility and this immunity are, nevertheless, real Mendelian unit characters, so real that by applying the Mendelian laws, susceptibility to rust has been bred out of English wheat.

May we not hope for a similar control of the immunity of cancer in the human family? Undoubtedly, though, the way has only been opened.

There are two consoling features about this knowledge with regard to the behavior of cancer: (1), that it behaves like a Mendelian recessive character, and (2), that it needs a stimulus to get a start, as with the English wheat in question which *needs the fungus parasite before the disease can be developed*.

REFERENCES

²¹J. A. Thomson, *Heredity*, 1908.

²²*Op.cit.*

CHAPTER IX

HEREDITY AND THE EUGENIC CLAIM

In the natural sciences, as in other branches of learning, acquisition of new knowledge is followed by practical application. This practical application lies not only in the order of material improvement and progress or "the harnessing of nature's resources," but also in agencies and institutions which deal directly or indirectly with human conduct. This is especially true of modern biology. Though it is only in its infancy, biology has made its influence felt in almost every sphere of human life. That man's bodily welfare has been promoted with the advance of biology needs no proof. The influence of modern biology, however, does not stop there. It has worked its way into the higher order of human life, into the psychological and moral domain, into those disciplines which deal, broadly speaking, with human conduct.

WHAT IS EUGENICS? Today, when biologists have really learned something regarding heredity, this tree of biologic science has cast its seed-bearing fruit into the garden of education, sociology, and kindred fields. In fact, it has already grown into a tree of its own, hailed by some as the tree of knowledge, decried by others as the tree of the forbidden fruit: *Eugenics*.

GALTON AND EUGENICS. Eugenics is the practical application of our knowledge of heredity to the human race. The word, meaning "well born," was coined in 1883 by Francis Galton in his book, *Inquiries Into Human Faculties*. It is only fair, then, to go to him for the definition of the much-discussed term. He says: "Eugenics is the study of the agencies under social control, that may improve or impair the racial qualities of future generations, either physically or mentally." And in another place: "I take eugenics very seriously, feeling that its principles ought to become one of the dominant motives in a civilized nation, much as if they were one of its religious tenets. . . . Man is gifted with pity and other kindly feelings, but he also has the power of preventing

many kinds of suffering. I conceive it to fall well within his province to replace natural selection by other processes that are more merciful and not less effective. This is precisely the aim of eugenics. Its first object is to check the birth rate of the unfit instead of allowing them to come into being, though doomed in large numbers to perish prematurely. The second object is the improvement of the race by furthering the productivity of the fit, by early marriages and the healthful rearing of their children."²³

In the last definition, Galton advocates clearly two distinct programs: (1) he would encourage the reproduction of the best, and (2) prevent the mating of the unfit. Through the first, he hoped to augment the numbers of the eugenically superior strains. Through the second, he hoped to avoid further contamination of normal families and to bring about the gradual reduction of defective ones. It is evident that these are two distinct programs. The first is sometimes spoken of as *positive* or *constructive eugenics*, the second as *negative* or *restrictive eugenics*.

PRESENT-DAY EUGENICS. That the modern eugenists still cling to the same program was made clear by Major Leonard Darwin, the English leader in this field. In the Second International Congress of Eugenics, held in 1921 in the City of New York, he made the following declaration: "I hold that our aim as eugenists should be to increase the rate of multiplication of stock above the average in hereditary qualities and to decrease it among the less fit. Others may wish to make our efforts cover a wider field, holding; for example, that the immediate benefits likely to arise from the teaching of sex hygiene should be included. With such as these I shall not quarrel for I am in full sympathy with their aims. But I do think that as a matter of convenience it would be well to restrict the meaning of 'eugenics' so as to make it cover no more than was intended by Sir Francis Galton who coined the word, that is, that it should apply only to measures affecting the inborn qualities of future generations."

Here it may be well to call attention to a common misunderstanding. Issues, for example, such as sex hygiene, birth control as an economic measure, and kindred doctrines, are really not part of the eugenic movement, though it is true that probably most eugenists are in sympathy with such teachings. It is not,

therefore, necessary in this discussion to enter into all such possible auxiliary ideas that various eugenists may bring forth.

Professor Guyer, of the University of Wisconsin, one of the most conservative and ablest leaders in the eugenic movement in America, has probably given the clearest definition by saying that the "science of eugenics concerns itself with race betterment through good ancestry." "The fact is undeniable," he continues, "that there are individuals endowed by heredity with good physical and mental attributes, and there are those who are constitutionally inferior in one or the other, or both of these respects. The eugenicist simply points to the desirability of having more of the first, fewer of the second type. He recognizes that the question of breed, of the natural endowment of its citizens, is of fundamental importance to any nation."²⁴

We have given these lengthy quotations for two reasons: (1) because we desire to be fair in our statement to both sides, and (2) because we wish to arrive at the very heart of the problem from the *biological point of view*; namely, that it is the theory of heredity on which the eugenicist builds his structure of social and racial reform. Emphasis is laid upon the "biological point of view," because there are several other points of view from which eugenics may be considered, such as, for example, the sociological and even the moral angle. What is biologically correct in the organic world, may neither be feasible nor morally permissible in its application to the human race. It is not, however, part of our object to discuss these angles of the problem, for that must be left to the sociologists and the ethicist whose interests lie in those fields. To keep the essential issue clearly in mind, let us restate and formulate the problem in the following manner:

THE EUGENIC ASSUMPTIONS

The eugenicist assumes:

1. That the human race is deteriorating at a rate of speed and to such an extent that, unless drastic measures are put into effect immediately, the final downfall is inevitable.
2. That the remedies, in order to be effective, must strike at the essential causes of this supposed deterioration.
3. That the essential causes of the deterioration are heredi-

tary, that is to say, that these causes have become part of the germ plasm in a great number of families, and are therefore transmitted from generation to generation.

4. That, therefore, the "tainted families" or strains must be made to die out, and that the sound and healthy families or strains must be made to make up the corresponding loss in birth by an increased birth rate.

This is a fair and just statement of the case on which we may build our discussion.

THE DETERIORATION OF THE RACE. There seems to be an ever-increasing flood of defectives and of social wastage, not only in this country, but in all parts of the civilized world. To get the angle of the eugenist in this matter, it must be pointed out that his argument is not based on the *absolute* increase of the so-called undesirables, but rather on the *relative*, or better, the *proportionate* increase of such a class. That is, that defectives of all classes have increased and are increasing at a greater ratio than the normal or fit classes of the population increase. In England, for instance, the ratio of defectives to normal is said to have more than doubled between the years 1764 and 1896, though it may be doubtful whether the statistics of those days, even in England, had a sufficient degree of accuracy to be relied on for any such generalization. In the United States, the rate per 100,000 of population of patients with mental disease under institutional treatment increased from 118.2 in 1890 to 220.7 in 1920. Statistical investigations on epileptics in the State of New Jersey indicate that this class of defectives doubles about every thirty years. In the criminal element throughout the country, the proportionate increase is even greater. In 1890, for instance, there were only 131.5 out of every 100,000 of our population in penal institutions, whereas in 1910 alone there were committed to this class of institutions 531.7 persons out of every 100,000 population.

A similar proportionate increase is to be noted among all classes of insane and feeble-minded people. A conservative estimate places the total number of insane in the United States today at 250,000; the number of feeble-minded of all degrees at at least 300,000; the number of epileptics at about 200,000. The

total number of dependents, meaning such people as are unable to earn their own living, was placed, in 1910, at approximately three million, or one in every thirty of our population. The upkeep of this army of dependents, defectives, and degenerates is, of course, enormous. The State of New York is spending for her insane alone one fifth of her total revenue, in the Commonwealth of Massachusetts, about one third of the entire state income is being spent in the support of individuals requiring state care. In other states it is not much better. There seems to be little doubt that the various states of the Union pay *directly* well over \$100,000,000 every year in support of their defectives and degenerates. This is an appalling situation, but the worst of it is, that this class of people has a considerably greater birth rate than the rest of the population. In fact, their birth rate is just about twice that of the desirable element of the population.

It is here that the eugenicist finds his strongest point of attack. "Why this increase of defectives?" asks Professor Guyer. "It cannot be attributed to oppression, to grinding poverty, or to decline in attention to our sick and needy, for never was prosperity greater, never were charities more flourishing, never such activity in the search for palliatives and cures. The simple fact is that we *are breeding our defectives* . . ." ²⁴ In other words, the eugenicists say that the reason for this excessive increase is due to the fact that these defects are hereditary and that the affected families average more children than the rest. In this connection, we have to point out that, according to the eugenicist, there exists a direct relationship between crime and mental abnormalities and defects. According to him, the great majority of criminals are such because they are mentally deficient. Now, it is true that these defectives have larger families, but it really should be put the other way around; namely, that the more desirable are having continuously smaller families. This puts the cause for the *proportionate* increase of "eugenically unfit people" in the right place, that is to say, on the shoulders of those who, eugenically speaking, should have larger families. Furthermore, the relative increase is not as great as it seems to be. With our improved methods of sanitation and care for the

sick, the pauper, and the defective, these classes have been freed in part from the stress of an environment that, under previous conditions, resulted in their premature death. In other words, we are saving more of the weaker element than was the case years ago, thereby swelling their relative numbers.

CRITICISM OF THE EUGENIC CLAIM

But let us look into the essential part of the problem. Are these defects really hereditary? Let us begin with mental diseases. We may classify them into two broad groups; namely, *amentia* and *dementia*. Amentia means that he who suffers from it has never had a developed mind, that is, he is an idiot or an imbecile, or was feeble-minded from birth; while dementia means that he who suffers from it had a more or less normal mentality, but later lost it.²⁵

MENTAL DISEASES. Dementia, which comes only after a mind has had already some development, can come about only through one of two causes: it must be due to either accident or disease; whereas, in the case of amentia, that is, where an individual is born without a mind capable of partial or full development, it is assumed that neither accident nor disease in the individual himself has had anything to do with it.

But there is no scientific evidence that imbecility, feeble-mindedness, and idiocy are fundamentally different from dementia.²⁶ The last word in scientific medicine seems to indicate that the conditions which we call diseases, in whatever part of the body they may occur, are due to the action of microörganisms, to malnutrition, or to physical injury. In Chapter VIII, it was pointed out that there is no such thing as heredity of specific diseases. The question, then resolves itself into: Are amentia and dementia diseases? Very little accurate work has been done along these lines, but what has been done points unmistakably to the conclusion that amentia and insanity are diseases.

One of the best studies on this question is contained in a report on 1,180 post mortems of the insane at the State Hospital for the Insane, Norristown, Pa., by Dr. H. J. Sommer, Jr. In all of the cases in which a record was kept, 1,163 in number, a change in one or more of the serous membranes of the body was recorded, and in 842 cases in which the brain had been examined,

there was either chronic inflammation of the outer covering of the brain, or inflammation of the inner covering, or of both. It may be well to state here that such inflammations are caused usually by the action of microorganisms or the toxins of microorganisms inhabiting the brain or its membrane or important organs of the body. Most of the cases had one serous membrane of the body affected; the serous membrane lining the inside of the heart was quite commonly affected, and a great many had inflammation of the kidneys. As the kidneys are chiefly concerned with the elimination of toxins from the body, the frequent breaking down of these organs in mental diseases is in itself ground for suspicion that toxins are responsible in some way for the conditions.

Similar conclusions have been reached by Dr. D. J. McCarthy at the Henry Phipps Institute. His work seems to indicate that the toxins liberated during tuberculosis, whether by the tubercle bacillus itself or from the microorganisms associated with it, set up changes in the membranes of the brain and, in all probability, cause insanity. In a histological study of 287 brains of people who had died of tuberculosis, he found acute inflammation of the inner membranes of the brain 49 times. The clinical study of these 49 patients had shown a change in mentality which, in quite a number, amounted to insanity.

The significant feature in these studies is that these changes in the serous membranes existed both in the cases of insanity and of amentia, and that they were the same in both young and old. In a girl idiot of only twenty months, there was a chronic inflammation of all the membranes of the brain and of the inside lining of the heart. This is very significant!

Admitting that it has not been proved that the changes in the membranes and tissues of the brain and in other serous membranes are the cause of amentia and insanity, the existence of these changes in all cases of amentia and insanity and their absence in the majority of people who die from other diseases, gives us a working hypothesis and throws serious doubt upon the theory of heredity of these mental abnormalities. To say the least, such findings give more than reasonable grounds for assuming that such conditions are actually diseases.

The acceptance of the theory that a microörganism is the direct or indirect cause of mental diseases is much more in harmony with what is now definitely and accurately known about diseases generally, than to accept heredity in these cases. The microörganic theory also does not come in conflict with biological principles as the theory of heredity of these conditions does. The whole theory of the heredity of disease is crumbling away in the light of scientific medical investigations.

A similar opinion was lately expressed by Dr. Harry C. Solomon of Harvard University. In a recent address he said, "While there is little reason to doubt that there are certain families in which mental disease is transmitted from generation to generation, such instances are quite rare. . . . It has not been possible as yet to apply Mendelian principles of heredity to human mental diseases."

With the heredity of mental diseases in very grave doubt, there is no need of arguing about the possible good that could be accomplished by putting into practice the various measures advocated by the eugenicist. Since all these measures are of an extraordinary nature, such as to interfere with the recognized rights of the individual and of his natural functions, it is up to the eugenicist to prove that they are justifiable. The burden of the proof is on him, not on those who are opposed to these measures.

Because of a common belief that various forms of degeneracy and other defects are hereditary, the eugenicist has jumped to the conclusion that he has a cure for them. He is logical enough when he says that *if* they are hereditary, society can stamp them out by putting into effect measures which will prevent those affected from becoming parents. But he is building upon a wrong premise.

He has looked to the genetic biologist to furnish the proof, but in doing so, he has blundered. He has even led another good man astray. For, the student of heredity is not in a position to deal even with the more complicated bodily traits of man, much less these complex mental characteristics, at least not if he is to remain true to the exacting methods of scientific procedure. In their attempts to lend the eugenicist a helping hand, the biologists have again lost sight of the experimental character of their science. Probable conclusions, wild guesses, and speculations that claim to

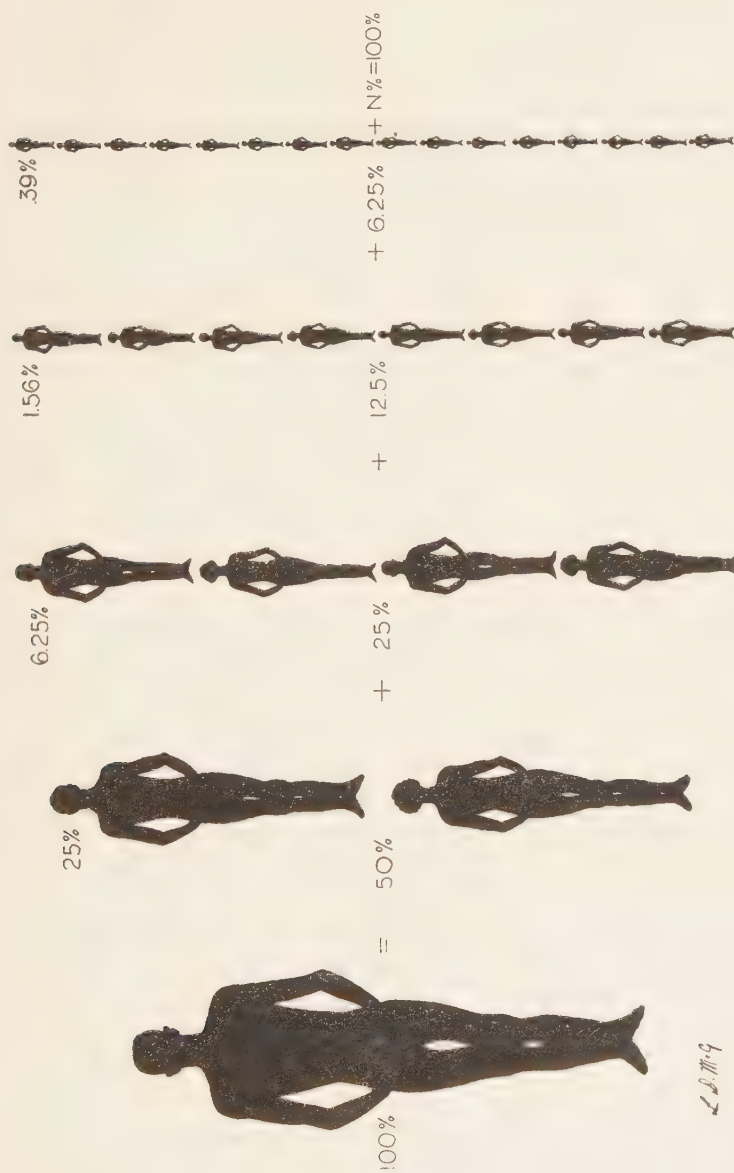


FIG. 44

Diagram illustrating Galton's Law of Ancestral Inheritance.

be scientific are already filling textbooks on genetics. In reading the chapters in these books which deal with such topics as "Heredity in Man," "Heredity of Mental Defects and Diseases," "Heredity and Crime," and those of similar import, one cannot but come to the conclusion that the authors of these texts cheapen their science and transform supposedly scientific texts into low-grade books on sociology:

After these authors call attention to the immense difficulty of obtaining reliable data on the matter, the authors proceed to tell the reader that there is, however, no doubt that the various forms of insanity, feeble-mindedness, alcoholism, and that inevitable bugaboo of eugenics, *criminal tendency*, are inherited. Since such books claim to be biological, one naturally looks for biological proof, but all one finds are groups of statistical figures.

FALLACY OF ANCESTRAL INHERITANCE. The statistical method of investigation has its place in sociology where one deals with groups, but not in biology where the law is supposed to apply to the individual. A good illustration is afforded by Galton's *Law of Ancestral Inheritance*, which was formulated on the basis of extensive studies on selected traits of certain families. It may be stated thus: The two parents contribute between them on the average one half of each inherited character, each of them contributing one quarter of it. The four grandparents contribute among them one quarter, or each of them one sixteenth; and so on, the sum of the series one half, one quarter, one eighth, and one sixteenth . . . being equal to one, as it should be. (See Fig. 44.) The average contribution of each ancestor is thus stated definitely, the contribution diminishing with the remoteness of the ancestor. Now this law may be true of the average in a very great group, but it is not true of the individual. We know now that we do not inherit equally from all our ancestors; on the average we inherit about as many traits from our fathers as from our mothers, but inheritance from the four grandparents is usually unequal and the further back we go the more ancestors we find who have contributed little or nothing to our inheritance. This disproves Galton's *Law of Ancestral Inheritance*. Quite a blow to those who pride themselves on their blue-blood pedigree! One may be a direct descendant of a Mayflower pil-

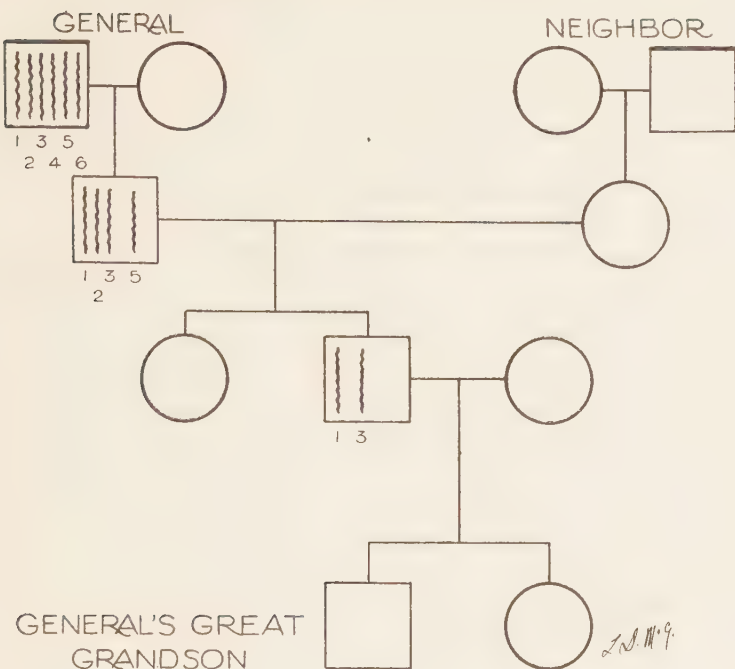


FIG. 45

Diagram showing how the determiners of different traits can be lost in successive generations. 1 to 6 represent chromosomes of the great-grandfather; chromosomes of the female line not shown.

grim, and yet not be related to him or her in any biological sense of the word at all ; he may have nothing at all from that ancestor except the honor of being related in a popular sense.

How quickly a family may lose the biological inheritance of a famous, or, for that matter, infamous ancestor—it fortunately works both ways—may be seen by studying Figure 45.

In this diagram, the square with the six wavy lines represents the part of the inheritance of a father whom we suppose to be a great general with unusual qualities. Each wavy line represents a chromosome containing the determiner for one of his outstanding qualities. The square in the second row represents the heredity of his son, who is fortunate enough to receive chromosomes 1, 2, 3, and 5 from his famous father, but loses chromosomes 4 and 6, these being replaced by chromosomes from the mother.

who by supposition is of "average" quality. The son now marries the neighbor's daughter, as is often the case. Their son in turn receives only chromosomes 1 and 3, and has, therefore, only two of the great qualities of his grandfather. The grandson now marries a woman of average qualities, and the son of this union is seen to have none of the chromosomes containing the qualities which made his great-grandfather so famous. In these traits, he has no genetic connection with him, and you will recall that that is exactly what is meant by heredity—genetic connection between successive generations. This fact throws an unsurmountable obstacle in the way of the eugenic desire to "breed a race of supermen," and shows the futility of the so-called eugenic babies. The random shuffle of the chromosomes, which takes place before the union of the germ cells, makes the result merely a matter of chance, an idea well expressed in the little poem of the biologist:

"Oh chromosomes, my chromosomes,
How sad is my condition!
My grandsire's gift for writing well
Has gone to some lost polar cell
And so I write this doggerel,
I cannot do much better."²⁷

REAPPEARANCE OF CHARACTER IS NOT HEREDITY

By observation alone, it is impossible to distinguish between inherited and environmental resemblances and differences. Yet this distinction is essential to any valid study of heredity, in fact, it is the very question at issue. Most statistical investigations of heredity beg the question by assuming that a given trait, because it continues to reappear in a family, is thereby inherited, forgetting that reappearance is not synonymous with heredity. We have only to recall to mind such diseases as malaria, yellow fever, etc., which were assumed to be inherited till their cause was discovered. A character reappears because it is either hereditary, or environmental, or both, but statistics can never tell us which it may be. This drawing of conclusions from statistical studies as to inheritance of traits leads only to confusion. No two investigators agree on their findings in the sta-

tistics which deal with human conduct or the higher functions of man. One may tell you that 50 per cent of all criminals are subnormal, the next one may reduce it to 20 per cent, and the third may feel that only 5 per cent are subnormal.

The following editorial of a Boston paper puts the matter rather well under the heading of "Who's Looney Now?" Says the editorial: "The State's attorney in the Hickman trial produced a number of 'experts' who called the defendant sane.

"Eddie's lawyers trotted out a like number of learned lads who dubbed him mentally diluted.

"The jury credited the alienists for the State and thus was justice attained.

"In practically every important murder trial in this country since Delphian Delmas, defending Harry Thaw, advanced the terms 'dementia Americana' and 'brainstorm,' the public has been affronted by the spectacle of opposing ranks of psychiatrists, for the State and the defense, all equally 'eminent,' confusing jurors and befuddling the issue with volleys of complex, scientific terms which, when analyzed, are found to be mere expedients for concealing the lamentable truth that there exists no satisfactory criterion of sanity or insanity. . . .

"Some years ago a man declared sane by alienists in one state and insane by 'experts' in another provoked country-wide mirth by the query: 'Who's looney now?'

"The question is still unanswered."

The National Crime Commission gave *one answer* to this query in a report in which the prevalence of crime in the United States was said to be due mainly, not to the subnormal state of mind of the criminals, but to "the lack of average intelligence in the police force, particularly in the supervisory branches." The unfortunate police force of Cleveland, Ohio, was singled out as a prime example. An Army intelligence test given in Cleveland revealed:

Three per cent of the patrolmen possessed Class A mentality (as against 9 per cent of the privates in the U. S. Army).

Not a single detective possessed Class A mentality.

Four per cent of the detectives were Class B.

Twenty-five per cent of the detectives were Class C.

Twenty-five per cent of the detectives were of markedly inferior mentality.

Thirty-three of the patrolmen had average intelligence.

Twenty-five per cent of the patrolmen were morons.

The report said that "the percentages . . . are so low that one no longer wonders why so many individuals turn to crime. It would appear to be about the safest business in which one could engage."*

It is extremely difficult to find out what is meant by "inherited criminal tendency." In the first place, crime is a lawyer's term and has no natural definition. It is therefore defined differently in different states and countries. If one means by a criminal tendency that there is a more or less pronounced tendency in all of us to do something unusual, something out of the common run of things which will focus the attention of our fellow men upon us, we heartily agree. But whether the unusual thing is performed by means of the Crucifix of the pioneer missionary or by the dagger of the bandit, whether it is made by the tool of the artisan or by the revolver of the gangster, whether it be made in the dungeons of the underworld or with the "Spirit of St. Louis" soaring through the sky—these things depend not on heredity, but on environment, training, and will power.

One can readily understand that a great confusion can easily creep into the subject, due to a looseness of terminology. Such expressions as "this or that trait has undoubtedly an hereditary basis," or "heredity sets bounds about us which we cannot pass" usually have no meaning at all and are wholly out of place in a discussion of heredity. Of course, everything must have a hereditary basis, one cannot take a dollar out of one's purse unless there is one there to be taken out. But that dollar may be in paper, or silver, or made up of small change.

Many authors speak as if a trait were a fixed character in the germ cells, whereas they should know that the actual thing which is transmitted by means of the germ cell is not the character itself at all, *but something which will develop into the character in the offspring*. The determination of each character and the way it is to manifest itself is, however, essentially influenced or modified

**Time*, March 12, 1928.

during the development in any given environment. This was well illustrated in the first two experiments with the beans (Figs. 33 and 34) where size was the character studied. We saw how differently such a character developed in different environments. Adult characteristics are *potential* and *not actual* in the germ cell, and their actual appearance depends upon many complicated reactions of the germinal units with one another and with the environment, the latter beginning not at the time of birth, but at the very moment of fertilization or even before. Our *actual* personalities are not predetermined in the germ cells, but our *possible* personalities are. *There are many possible personalities in each of us, and what we actually are, is not always what we might have been.*

HEREDITY NOT DETERMINISM. There is nothing in our present knowledge of heredity and development that would force us to change our fundamental conceptions of the value of training, education, and the importance of good environment in the broadest sense of the word. It is still true that acts, if repeated often enough, will become habits, and that habits, in turn, form character. It is still true that men are free to do right or wrong and that they are responsible for their deeds. Example, good or bad, still retains its powerful influence on the formation and development of character. High ideals will still uplift youth; duty and truth are still realities. In short, heredity does not mean *determinism*, though some biologists would have it so. The modern extreme view of heredity is nothing but "Calvinistic predestination in scientific guise," and it is no less an absurdity because it struts around in an academic gown instead of a minister's robe.

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CHAPTER X

ORGANIC EVOLUTION

THE TERM "EVOLUTION"

Present-day writings are saturated with the concept of evolution. In one breath, we speak of the evolution of the stars, of the horse, of the steam engine, of the evolution of literature, of society, and of religion, as though they were part and parcel of one and the same process. With Professor Morgan, we may well ask and answer: "What have they in common? Only this, that each concerns itself with the *history* of something . . . that from a simple beginning through a series of changes something more complex, or at least different, has come into being. To lump all these kinds of changes into one and call them evolution is only to assert that you believe in consecutive series of events (which is history) causally connected (which is science). It is the aim of science to find out *specifically what kinds* of causes were at work when the stars evolved in the sky, when the horse evolved on the earth, and the steam engine was evolved from the mind of man."²⁸

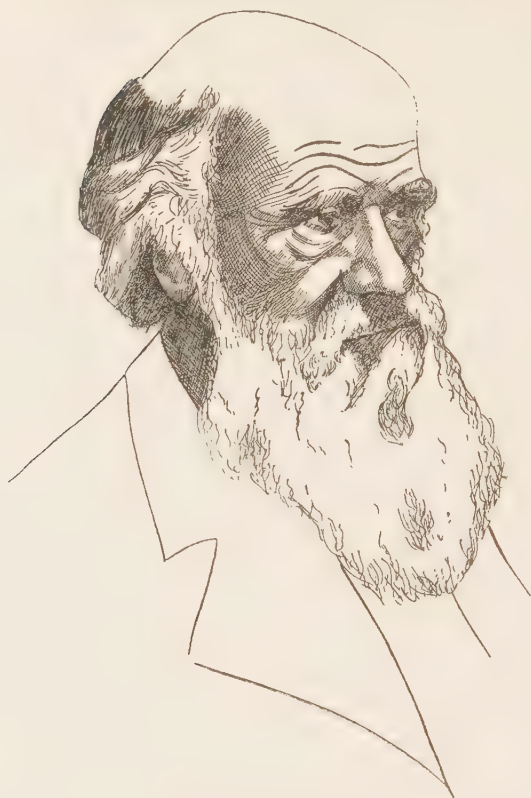
In this causal sense, we speak correctly of inorganic and organic evolution, meaning in general that things have changed and are constantly changing. The stars, the earth with its minerals and rocks, the plants and animals, have not always been what they are today, but they have undergone a continuous, gradual change, and this gradual change has taken place and is taking place under the guidance of definite, natural laws. The discovery and working out, the unraveling of these guiding and controlling laws is the purpose and aim of evolutionary science.

This concept of an everchanging world is already found in the writings of some of the old Greek and Latin authors. But it became a potent factor only during the course of the last century, when it was specifically applied to the organic world—to plants and animals. In this form, it is known as the doctrine of "organic

evolution" or the "theory of descent," and means that plants and animals have developed in a continuous, orderly way from lower to higher stages, or that the present forms of plants and animals are the *modified* descendants of earlier organisms. Opposed to this view is the doctrine of "creationism" or "fixism" which suggests itself as the natural interpretation of the Biblical account in the Book of Genesis. This view was held by the famous Swedish naturalist, Linné. In fact, he made it the very foundation of his masterpiece, *Systema Naturae*. He claimed that no specific change is possible in animals and plants, that all organisms have persisted in essential sameness of type from the beginning of organic life to the present time. Or, to use his own phrase: "We recognize as many species as were originally created."

To restate the case. On the one hand, we have the point of view that the members of a species may indeed vary among themselves, but they cannot vary or change to such an extent as to exceed the boundaries of their particular species or natural group, therefore, they cannot become the ancestors of a new species or group of organisms. On the other hand, we have the point of view that plants and animals have undergone changes exceeding all specific boundaries with this result, that the present-day forms are totally different from their own ancestors, the difference increasing with the length of time elapsing. As understood today, this change, this modification, is of a progressive character, that is, it proceeds from the simpler to the more complex or more perfect. Pushed to its logical conclusion, it postulates one common ancestral form for all organisms today, so that the plants and animals of our day are *highly modified descendants* of one common ancestor. Therefore, such an explanation is called the "*theory of descent*."

It is rather interesting that the doctrine of organic evolution received its first real impetus through the work of the illustrious Frenchman, Georges Cuvier, who was himself staunchly opposed to it until his very death. In his investigation of extinct mammals of France, he found the older fossils (older as regards the era in which they are found) belonging to entirely different species and genera from the animals existing at the present time, the difference being greater in the deeper (older) than in the more super-



CHARLES DARWIN (1809-1882)

Originator of the Theory of Natural Selection

No scientific man has probably been more lavishly praised and more heartily condemned than Charles Darwin. The latest authentic History of Biology gives the following objective judgment: "Even on his first appearance, he was either extolled as one of the greatest geniuses in the world or abused as an ignorant and unreliable dilettante, according to the different points of view. Nor have subsequent generations been any more unanimous; especially since the theory of selection has been condemned, at least in its original form, hard words have not been spared against its creator; as a matter of fact, a natural reaction against the adoration meted out to him towards the close of his life, which received confirmation in his being buried beside the grave of Newton. Was this apotheosis justified or not? To raise the theory of selection, as has often been done, to the rank of a natural law comparable in value with the law of gravity established by Newton is, of course, quite irrational, as time has already shown; Darwin's theory of the origin of species was long ago abandoned. Other facts established by Darwin are all of second-rate value. But, if we measure him by his influence on the general cultural development of humanity, then the proximity of his grave to Newton's is fully justified."—Erik Nordenskiöld, *The History of Biology*, Alfred A. Knopf, 1928.

ficial (younger) geological formations. He thus introduced the idea of *definite succession of life in time*. Although Cuvier rejected the notion of any genetic connections (descent) between the inhabitants of successive geologic periods, he, nevertheless, paved the way for the reception of Darwin's views some fifty years later.

The name of Darwin is so conspicuously connected with the history of organic evolution that, to many, evolution and Darwinism are synonymous. This is, however, erroneous. Not a few naturalists before him thought out clearly and stated definitely the idea of organic evolution. There had even been a number of theories advanced before his day to explain such a doctrine. For instance, St. Hilaire and Lamarck in France, Goethe in Germany, and Darwin's grandfather, Erasmus Darwin, had done this very thing. Charles Darwin, however, was the first to formulate a specific theory of organic evolution which was sufficiently startling to attract general attention. It is best known through the "catchy" phrase "the survival of the fittest in the struggle for existence by natural selection." The publication of this theory, in 1859, marks the beginning of evolutionary thought as we now understand it not only in the natural sciences, but in all fields of study.

BACKGROUND FOR DOCTRINE OF ORGANIC EVOLUTION

Throughout our own lives and as far back as we have any written records, we have seen no evidence that organic evolution actually is going on. Or, to put it in another way, our own personal observations and the recorded observations of our ancestors force us to conclude that *organisms are constant within well-defined limits*, that they are not undergoing what is commonly called a "specific" change. As far as you and I can see, and as far as our ancestors have left us their observations, a dog has always been the parent of a dog, a cat always of a cat, a rose always of a rose, and a thistle always of a thistle. Since actual observation of specific organic evolution is not the basis of this doctrine, how did men get this notion of an organic evolution?

PHILOSOPHICAL BACKGROUND. Science is said to be *organized* knowledge. This means, that one may know thousands upon thousands of individual facts or data in a given branch of learn-

ing, and yet have no *scientific* knowledge of the subject. Such has actually been the case in the study of biology until comparatively recent times. It is, of course, true that men were always interested in the activities of living beings, and that many excellent observations had been made as early as the days of the Greek philosopher, Aristotle, who lived about 350 years before Christ. But up to about a hundred years ago, this accumulated knowledge was like so many bricks scattered about in hopeless confusion, these bricks had not been gathered and put in the form of a building for the simple reason that there was no plan according to which one could build this much-desired temple of the science of biology. What the architect's plan is for a building, so a general principle or theory is for a science. It organizes knowledge into a definite unit by bringing a great number of individual data under one uniform and common explanation. The theory of organic evolution (common ancestry of all organisms) was the first attempt to formulate such a general unifying principle for biology. The cell theory is another example.

At this point, it is well to try to evaluate the theory of organic evolution. There are two methods by which a principle may be formulated, by *inductive* and by *deductive reasoning*. Natural science, being based on what we can observe with our senses in nature or in the laboratory, obtains its principles by inductive reasoning. By inductive reasoning is meant the method of natural science of collecting all data possible in regard to a subject. From such facts is then derived some underlying law or principle which holds them together. Such an underlying law is said to be a *scientific principle* in contrast to a *philosophic axiom* or principle arrived at by *deductive reasoning*. In this latter case, the principle is first formulated and then applied to explain facts as they pass in survey.

IS ORGANIC EVOLUTION A "SCIENTIFIC" PRINCIPLE?

If so, it must have been formulated by the inductive method, which is the only scientific method. As already stated, in this method we proceed from actual observation of individual cases and attempt to infer, from these individual observations, an explanation which we can apply to the whole. A good example of a principle or theory obtained in this manner in biology is the cell

theory. This theory was conceived through observation of the thing itself; that is, cellular structures were actually observed in many individual instances. From these individual instances, the conclusion was drawn that all living forms *might* consist of similar cellular units. Such a conclusion is known as a "hypothesis." The hypothesis is then tested by extensive observations and found to be actually correct. In other words, the hypothesis worked and was verified. It became a theory—a scientific principle.

That there is nothing of this nature in the doctrine of organic evolution becomes clear when we consider two important points. First, let us look at the arguments brought forth in support of the theory. They are taken from (1) paleontology (the study of fossil remains), (2) comparative anatomy (the study of similarities and dissimilarities in the structure of organisms), (3) embryology (the study of the development of the individual), and (4) genetics (the study of variations). Note the remarkable fact that these fields of biology were practically unknown in the days when the principle of organic evolution was first formulated. Secondly, it has never been shown that living organisms have actually overstepped the bounds of their species, either in nature or in the laboratory. As Vernon Kellogg says, "no indubitable cases of species forming or transformation, that is, of descent, have been observed."²⁹ We must, therefore, in fairness, admit that the principle of organic evolution is really a *philosophic* axiom or principle, not a *scientific* principle in the sense that the cell theory is such in biology or the atomic theory in chemistry. As a result, we are confronted by a vast difference between such principles. We may use the cell principle and the atomic theory legitimately to explain individual problems and to reduce them, if at all possible, to purely mathematical laws of explanation. On the other hand, in the case of organic evolution, the correlations are reversed and we are obliged to explain the individual problems to suit the theory. This is the prime reason why scholars of philosophical training can never agree with those not having such training on matters such as organic evolution.

IS ORGANIC EVOLUTION AN ESTABLISHED FACT?

While practically all biologists have come to the inevitable conclusion that we know nothing of the causes and modes of organic

evolution, and further agree that the *why* of it, the *explanation*, is as deep a mystery as ever, they are just as determined in their declaration that organic evolution is, nevertheless, an established fact. Now, however, "fact" may be used in two senses: We may mean by it an "observed or experienced event," or we may mean an "inferred event"; i.e., inferred from certain observations for the purpose of interpreting or explaining a particular phenomenon or a set of phenomena. It is certainly not valid to call organic evolution a fact in the first sense, since nobody has ever actually witnessed a case of organic evolution. To call organic evolution a fact in the sense of an "inferred event" may be legitimate so long as we admit the inference has no more force than the premises on which it is built. It is necessary, therefore, to examine briefly the data on which the conclusion rests.

ARGUMENTS IN FAVOR OF ORGANIC EVOLUTION

1. THE DATA FROM COMPARATIVE ANATOMY. Comparative anatomy is a study in which the various parts, structures, and organs of different organisms are examined as to their similarities and dissimilarities. In such a study, we are everywhere confronted by what is technically known as homology; i.e., a "basic structural similarity under a veneer of superficial unlikeness."³⁰ To use just one of a thousand examples, how can we explain that the foreleg of the frog, of the alligator, of the rabbit, and the wing of the bird are all built on the same basic plan? For, although they differ both in function and in external appearance, they are, nevertheless, made up of similar bones, similarly disposed with respect to one another (see Fig. 46). The organic world is full of such examples, many of them so striking that even a superficial observer must notice them. We cannot deny them, they confront us everywhere. The evolutionist insists on the application of the old rule that "like begets like." Brothers look alike because they come from the same parents, and by the same token, says the evolutionist, these structures in different animals are fundamentally alike, because these animals somewhere have had one and the same ancestor.

Criticism of Argument. The inference is certainly permissible and plausible, but it is not a necessary inference. Not all people

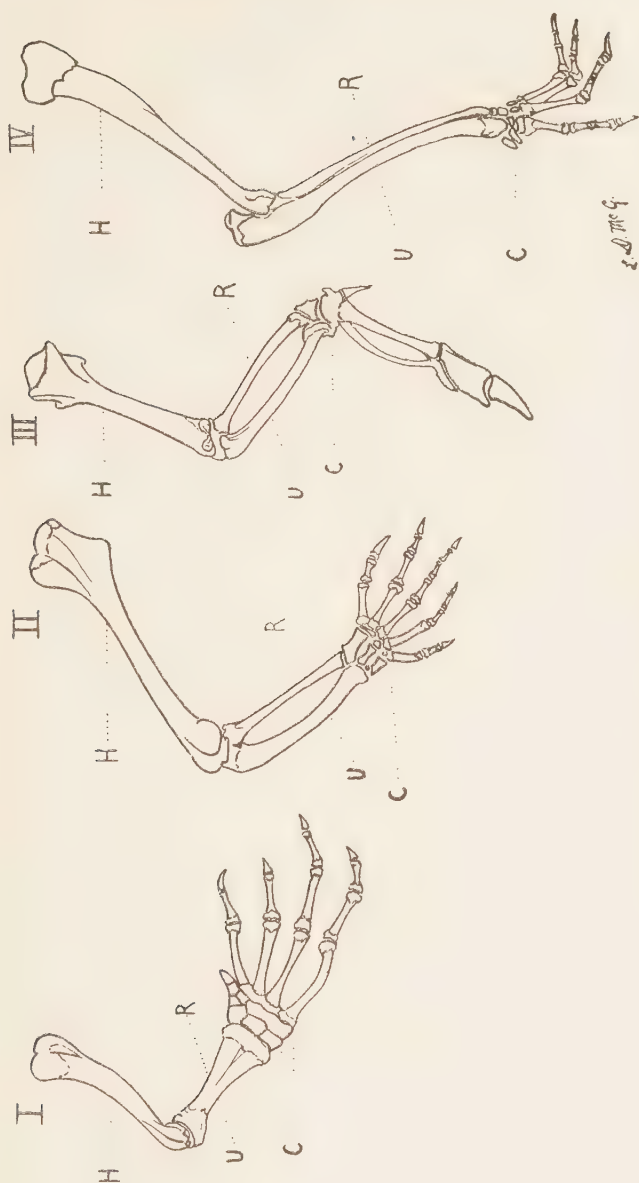


FIG. 46

Illustration of homology. I, forelimb of bullfrog; II, forelimb of alligator; III, wing of pigeon; IV, forelimb of rabbit—H, humerus; U, ulna; R, radius; C, carpals.

who look alike are brothers or sisters. It is not sound logic to build up the argument by saying "homology signifies a fundamental similarity of structure based on descent." To say that "when organs have the same ancestry, that is, when they come from some common part of an ancestral type, they are said to be homologous," is equivalent to making the absurd statement that all children born of the same parents look alike. They may look alike, they may not. O'Toole, in his book, *The Case Against Evolution*, says: "In thus confounding the definition proper with its theoretical interpretation, the modern biologist is guilty of a logical atrocity. Homology, after all, is a simple anatomical fact, which can be quite adequately defined in terms of observation; nor is the definition improved in the least by having its factual elements diluted with explanatory theory. And as for those who insist on defining homology in terms of atavistic assumption instead of structural affinity, their procedure is tantamount to defining the clear by means of the obscure, and actual effect by means of a possible cause."³⁰ Some would say that the course of such a method is due to the weakness of the argument. There is never any validity in a mere assertion that there can be only one intelligent explanation. It is a mere assertion to insist this is the only intelligent explanation. A basic similarity may be explained just as satisfactorily and just as intelligently on the assumption that the Maker employed a common, uniform plan in the creation of the different forms of life.

2. THE ARGUMENT FROM COMPARATIVE EMBRYOLOGY. Let us use a common example of the evolutionist (Fig. 47). Frogs lay eggs and from these are hatched, not frogs, but tadpoles. After passing through a series of complicated changes, these tadpoles reach the state of an adult frog. In the early days of their existence, however, the tadpoles have many fishlike characteristics. Instead of moving with front and hind limbs as the frog does, the tadpole moves about, like a fish, by means of a flattened tail. In addition, the tadpoles have, in their neck, a system of gills by which they breathe, as a fish does. These gills are gradually absorbed and are finally replaced by lungs. We may therefore say tadpoles resemble the fish in many structures and activities. From such resemblances, the evolutionist draws the following

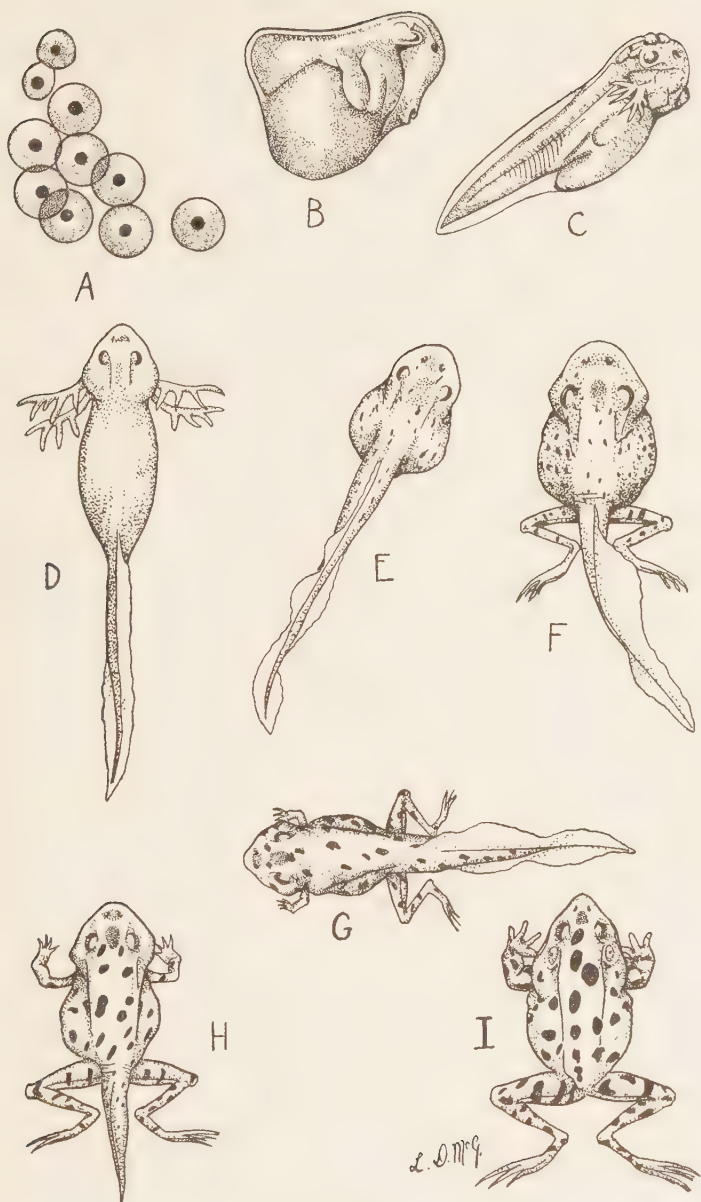


FIG. 47

Various stages in the development and metamorphosis of frog. A, eggs shortly after fertilization; B, tadpole at the time of hatching; C, tadpole with short external gills; D, tadpole with fully developed external gills; E to I, different stages of metamorphosis.

conclusion: The tadpoles have these fishlike characters because, in the remote past, frogs had fishlike ancestors. If we could trace the ancestors of frogs far enough, we would find that they attain fishlike form. The tadpoles just repeat, in these particulars, the history of their own race. Their fishlike characters are mere souvenirs of their earlier fishlike ancestors. This is the *Recapitulation Theory* or *Law of Biogenesis*, of von Baer, but popularized by Ernst Haeckel.

Criticism of Argument. This argument was considered by biologists of the past a very strong one in support of organic evolution. But its main advocate and formulator, Professor Haeckel, overdid the thing a little and thereby set some of the more independent-minded biologists thinking. What is the verdict today in the light of closer scrutiny? "Attractive as it sounds," admits Professor Newman, "there is reason for serious doubt as to the validity of this generalization."³¹ Professor Kellogg long ago called this so-called law "a skeleton on which to hang innumerable exceptions."³² Carl Vogt, an illustrious German biologist, says: "This law which I long held as well founded, is absolutely and radically false."³³ Professor Morgan, of Columbia University, rejects it as "in principle false."³⁴

3. THE ARGUMENT FROM PALEONTOLOGY. Paleontology is the study of the fossil remains of extinct animals and plants. Extensive discoveries in all parts of the world have brought forth clearly that there has been a *succession* of life in time; that is, that at different times in the history of the earth there have lived different kinds of organisms. In general, the fossil remains appear in such an order that the simpler forms are found in strata belonging to remote periods, while the more complex or higher forms are found in strata representing a more recent period in the history of the earth. The result is, that if we arranged the fossil remains of extinct organisms according to the time of their existence, we would obtain a scale very much like our classification of living forms—from the simple to the more complex. This succession of forms suggests to the biologist their *descent* from one another.

Criticism of Argument. Here again we must call attention to a fundamental distinction between two concepts on which the whole argument rests—*succession* and *descent*. Descent is not a corol-

lary of succession. An example may serve to make this clear. Let us suppose, with Bather,³⁵ that all records of English history were destroyed, and that we had only the English coins left. From these coins we could obtain a true chronological table of all the English monarchs, and in addition, we might suspect that the throne was hereditary. But if, on that assumption we were to make James I the son of Queen Elizabeth, or George I the son of Queen Ann, we would make a grave mistake. Now, this is exactly the plight of the paleontologist. He has no criterion by which to

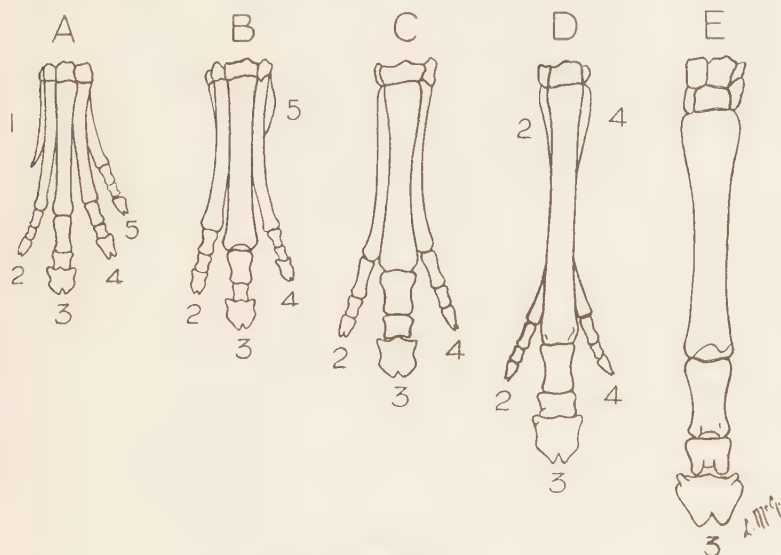


FIG. 48

Series of fossils illustrating various stages in the evolution of the horse's foot (redrawn after O. Abel).

control his interpretation of descent. Fossil remains furnish us only descriptions of what is found. *It is a dead account.* It can never give us an explanation. "The paleontologist cannot assist at even a single birth of a new species, the evidence remains circumstantial."³⁵ Take for instance the example represented in Figure 48. It is true that in successive strata fossil remains of "horses" are found with their feet developed as shown in this figure. But, it is not written, as it were, on these fossils that they are descended from one another; that is a mental conclusion. In

fact, it is impossible to assume that they are the direct descendants from one another, because nature does not make such sudden jumps. If they have descended from each other, there must have been a great number of intermediary stages, of which we have no records. In other words, there are, at the present time, no unbroken series of fossils; even the best are only fragmentary, there are too many "missing links." Furthermore, the paleontologists themselves insist their findings can be explained only *by assuming that acquired characters are inherited, and all evidence up to the present moment points against such an assumption.*

4. ARGUMENT FROM GENETICS. Finally, you may ask what about the "new species" that are constantly being created by the geneticist? Would these not furnish experimental evidence? Yes, undoubtedly they would, if they only were "new species."

Bateson, who made it his life's work to produce new species and thereby to establish experimental evidence for organic evolution, admits that "critically tested, we find that they are not distinct species and we have no reason to suppose any accumulation of characters of the same order would culminate in the production of distinct species. . . . Nothing that we have witnessed in the contemporary world, can tolerably be interpreted as providing the sort of evidence required."³⁶

David Starr Jordan expresses the same opinion when he says: "None of the created new species of plant or animal I know of would last five years in the open, nor is there the slightest evidence that any new species of field or forest or ocean ever originated from mutation, discontinuous variation, or hybridization."³⁷

All our highly advertised evidence from the fields of genetics and cytology has come to naught with the proper understanding of Mendel's laws of heredity. In this connection Professor Cautley has written these rather remarkable words: "In any case we do not see in the facts emerging from Mendelism, how evolution, in the sense that morphology suggests, can have come about. And it comes to pass that some of the biologists of greatest authority in the study of Mendelian heredity are led, with regard to evolution, either to a more or less complete agnosticism, or to the expression of ideas quite opposed to those of the preceding genera-

tion, ideas which would almost take us back to creationism.”³⁸ In other words, the finest, as well as the most scientific achievement of biology in the past century, Mendelian inheritance, disproves rather than proves organic evolution.

From these few critical observations we may well infer that the case of the doctrine of organic evolution is, to say the least, not quite so clear as some enthusiasts would like to believe. Whatever its value as a *working hypothesis* may be, however great its plausibility, it certainly is neither a *scientific* principle nor a fact established beyond all reasonable doubt. In a way, we can understand the solicitous attitude of biologists with regard to organic evolution. It is *their* mental child, born under hard labor. Furthermore, there is no doubt that the idea of organic evolution is indirectly responsible for the phenomenal growth of the various biological branches. It has acted as an invigorating stimulus to the spirit of investigation and has, directly or indirectly, led to many an important discovery. The doctrine of organic evolution has won, we may say, a warm spot in the hearts of biologists, and we may well ask whether sentiment is not sometimes interfering with clear vision and objective judgment. Not a few evolutionary biologists may well ponder over the words of Abraham Flexner, that “at every stage, even the great men yield, from time to time, to the metaphysical spell, the blunder of interpretation, or in their pride and enthusiasm, try to extort from facts more than they contain.”³⁹

THEORIES OF ORGANIC EVOLUTION

By theories of organic evolution we mean attempted explanations of how organic evolution (on the assumption that it did take place) came about. In other words, what are the modes and causes of the process? In the light of what has been said in the foregoing paragraph, it is not surprising to find that biologists have not been able to formulate any definite quantitative or mathematical laws regarding a process of evolution. It is true that many attempts have been made in that direction, but to no avail. A brief review of the principal theories thus far proposed will make this clear.

1. THE ENVIRONMENTAL THEORY. The first theory made *environment* the direct cause of change, that is, *environment* was

held to mold new forms. This theory is based on the correct observation that organisms do respond to changed environments, but its interpretation is erroneous since the evolutionary factor is located entirely outside of plant and animal. The main champions of the environmental theory were St. Hilaire of France, Goethe of Germany, and Erasmus Darwin of England. The theory never really progressed beyond its initial stage, and now it has only a historical value.

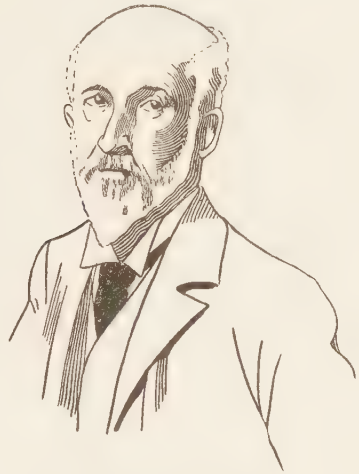
2. THE THEORY OF APPETENCY. A few years later, the Frenchman, Lamarck, announced his theory of the "effect of use and disuse," or, as he himself called it, the theory of "appetency." Here the direct cause of change lies in the organism itself, that is, in the striving and effort to do something rendered necessary on account of changed environment. In other words, environment is only the occasion of changes; the direct cause being within the plant or animal itself, the environment, as it were, assuming the rôle of arbiter. Aside from being far too general and unspecific to serve as a basis for a causal explanation, this theory rests entirely on the assumption of the inheritance of acquired characteristics, an assumption opposed to all present knowledge we have on the subject.

3. THE DARWINIAN THEORY. Next we witness the spectacular, epoch-making theory of Darwin, which was to become so potent a factor in the dissemination of evolutionary thought. Its main features are (1) that nature selects among variations, (2) that the method of selection is competition or "a struggle for existence," and (3) that the result of (1) and (2) is the destruction of the relatively unfit or "survival of the fittest." The Darwinian theory assumes as its fundamental law a spontaneous, fortuitous tendency in the organism to vary in all possible directions; further that these variations are so small and minute that singly they cannot be noticed at all, but that their continuous accumulation produces a marked change, which eventually leads to new species, genera, and so on. Dennert, an antagonist, in his *"At the Death-bed of Darwinism,"* points out the following characteristic traits of Darwinism:

"1. Evolution began and continues without the aid or intervention of a Creator.



RICHARD (1850-)
Ardent Defender of Darwinism



OSCAR (1849-1922)
Intrepid Opponent of Darwinism

THE HERTWIG BROTHERS

The Hertwig Brothers studied together at Jena under Haeckel, the foremost exponent of evolution in the Darwinian sense. After publishing a series of papers of fundamental importance, they separated, Oscar going to Berlin as professor of anatomy, Richard to Munich as professor of zoölogy. Their subsequent careers were full of discoveries of lasting significance and included extensive activities as teachers and investigators.

No two men in biological history illustrate so well **THE SUBJECTIVE CHARACTER OF THINGS EVOLUTIONARY** as do the Hertwig Brothers. Here are two men, brothers, sons of the same parents, possessing a similar hereditary background, both unusually gifted, and studying the same subject under the same man at the same university, also having a similar training and a similar environment. Both make the same investigations, check up on the same experiments, possess the selfsame facts, and each comes to exactly the opposite conclusion of the other in regard to organic evolution. With advancing years and knowledge Oscar became more and more doubtful even of the scientific value of the principle of organic evolution, while Richard grew stronger in his faith in this principle. In the evening of their lives each published a swan song: Oscar an uncompromising attack on Darwinism; Richard, an ardent defense of Darwinism.

"2. In the production of variations there is no definite law; chance reigns supreme.

"3. There is no indication of purpose or finality to be detected anywhere in the evolutionary process.

"4. The working factor in evolution is egoism, a war of each against his fellows: this is the predominating principle which manifests itself in nature.

"5. In this struggle the strongest, fleetest, and most cunning will always prevail. (The Darwinian term "fittest" has been the innocent source of a great deal of error.)

"6. Man, whether you regard his body or his mind, is nothing but a highly developed animal."⁴⁰

It is of interest to note that a theory devoid of all causal principles could have been received with such unbounded enthusiasm and could have been considered for almost half a century as the final answer to the problem of organic evolution. We must, then, take into account the peculiar character of Darwin's time, which was marked by intellectual unrest and social revolution. In those days, the minds of men, at least in the European countries, were ready to absorb anything that bore the stamp of radicalism, anything which would assist in opposing and tearing down the old established order. With a return to a truer evaluation of all human institutions, Darwinism as an explanation of organic evolution has steadily lost in standing among men of science. Today, we can say with L. Wiser that "anyone who has committed himself to Darwinism can no longer be ranked as a naturalist."⁴¹ The late Professor Bateson, himself an ardent evolutionist, had this to say about Darwinism: "Through the last fifty years this theme of the natural selection of favored races has been developed and expounded in writings innumerable. Favored races certainly can replace others. The argument is sound, but we are doubtful of its value. For us, that debate stands adjourned. We go to Darwin for his incomparable collection of facts. We would fain emulate his scholarship, his width, his power of exposition, but to us he speaks no more with philosophical authority. We read his scheme of evolution as we would that of Lucretius or of Lamarck, delighting in their simplicity and their courage."⁴²

There is, however, a very good reason for the obstinate uphold-

ing of Darwin's natural-selection theory. For, while there is, of course, an essential difference between organic evolution and Darwinism, yet it is true that this same doctrine of organic evolution was presented to the public on the crutches of Darwin's natural-selection theory. Now, these crutches have broken down beyond repair and the doctors are solicitous about their patient who has not yet learned to walk alone. Unfortunately, no new crutches have been constructed, so far, to take the place of the broken ones. But the public has become so accustomed to seeing the patient that it insists that he put in his daily appearance.

4. THE MUTATION THEORY OF DE VRIES. There still remains the mutation theory of the Dutch botanist, Hugo De Vries. According to De Vries, new species appear all at once in sudden jumps without the help of any intermediary or transitional forms. Nature, as it were, *pole-vaults* into new species. As with the Darwinian natural-selection theory, there was a meteoric rise of the mutation theory, only to come down with a sudden crash. The mutations in question do not fulfill the requirements of a specific change; they cannot even be regarded as an initial step in the direction of such a change. Professor Bateson has this to say with regard to De Vries's mutation theory: "But that particular and essential bit of theory of evolution, which is concerned with the origin and nature of species remains utterly mysterious. We no longer feel as we used to do, that the process of variation, now contemporaneously occurring, is the beginning of a work which needs merely the element of time for its completion; for even time cannot complete that which has not yet begun."⁴³

Thus we are justified in making the statement that all attempts to formulate any kind of scientific principle regarding the process of evolution has failed. Even the extreme enthusiasts of evolution admit this freely, though there are a few "die-hards" left who still cling to the antiquated theory of Darwin.

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CHAPTER XI

THE ORIGIN OF LIFE

In a previous chapter, the fact was emphasized that new cells arise only through a division of previous cells. Since the cell is the last unit of life, and since no life can exist except in the form of a cell, it stands to reason that life can come only from previous life in the form of a cell.

It is only natural that this principle, "every cell from a previous cell" should raise a very serious question in our mind. If, as is really true, a cell can come only from a previous cell, where did the first cell, the first life originate? This is the problem of the *origin of life*, and it should not be confused with the question of *reproduction*. The latter deals with the modes of new life from previous life, of a new cell from a cell already existing, of a new organism from an organism already existing.

Many clever and fantastic theories have been propounded for the solution of this question:

1. Flechner and Preyer insist on a theory that is known as "priority of organic matter." This theory holds that living matter existed in the universe before nonliving matter. According to these writers, the universe was originally a single living being, a sort of supergiant of life endowed with consciousness. From him arose, in time, the sun, the stars, the earth, and the various distinct forms of life including man. Aside from being too fantastic and altogether devoid of proof, this assumption leaves the problem unanswered. We still face the original question, only in a somewhat different form: Where and how did this supergiant arise?

2. Another group of writers have, from time to time, suggested that life may have come to this earth from some other planet by the agencies of meteorites and cosmic dust. The fact that spores, seeds, and all sorts of microorganisms are capable of withstand-

ing prolonged exposure to low and high temperature, and that they can exist for a long time in the almost complete absence of moisture and oxygen would, according to these authors, favor the possibility of particles of living matter making long journeys through space from one planet to another. Thus life might well have passed from one celestial body to another, reaching finally our own earth. This, of course, is all well and good, but it does not solve our problem, it pushes it only a little farther back. Our original question still confronts us: How did life start in the first place?

There are really only two ways in which the human mind can conceive life to have originated: *either by spontaneous generation, or creation.*

By spontaneous generation is meant the origin of living matter (*de novo*) from lifeless matter; in other words, the origin of life without previously existing life (abiogenesis). Note that this is in direct contradiction to the famous axiom of Virchow: *Omnis cellula ex cellula*—every cell from a previous cell.

THE GREAT HERESY OF SCIENCE

Up to about seventy-five years ago, it was the common belief among people at large as well as the educated world, that life arose spontaneously out of nonliving matter like water, air, and decaying substances. The writings of the older Greek and Latin authors bear ample testimony to this belief. Even Aristotle, who was a veritable fountain of knowledge in his time, said that animals were sometimes formed in putrefying soil, sometimes in plants, and sometimes in the fluids of other animals. The Roman poet, Virgil, has left us a detailed method of obtaining bees from the decaying body of an animal. Ovid, a later Roman poet, said that bees came from the bowels of a slaughtered steer; wasps and hornets from the claws of a crab; and frogs from slime. As late as 1600, the renowned scientist, Van Helmont, gave a detailed recipe for raising mice by putting some dirty linen and a piece of cheese, or some grains of wheat into a jar.

The first scientist to challenge successfully this common belief was the Italian, Francesco Redi (1626-1698), court physician and member of the Academy of Florence. He had often observed the

various stages of decay in meat, and was particularly struck by the great number of flies that hover around and alight upon decaying meat long before there are any maggots present. Being a thoughtful man he began to wonder whether a relationship might not exist between the flies and the maggots. So he set to work and performed a few simple, but significant experiments. It may be instructive to quote here his own interesting accounts of these experiments.

ORIGIN OF WORMS. "Although content to be corrected by any one wiser than myself, if I should make erroneous statements, I shall express my belief that the Earth, after having brought forth the first plants and animals at the beginning by order of the Supreme and Omnipotent Creator, has never since produced any kinds of plants or animals, either perfect or imperfect; and everything which we know in past or present times that she has produced came solely from the true seeds of the plants and animals themselves, which thus, through means of their own, preserve their species. And, although, it be a matter of daily observation that infinite numbers of worms are produced in dead bodies and decaying plants, I feel, I say, inclined to believe that these worms are all generated by insemination and that the putrefied matter in which they are found has no other office than that of serving as a place or suitable nest where animals deposit their eggs at the breeding season, and in which they also find nourishment; otherwise I assert that nothing is ever generated therein. And, in order, Signor Carlo, to demonstrate to you the truth of what I say, I will describe to you some of those insects, which, being most common, are best known to us.

"It being thus, as I have said, the dictum of ancients and moderns, and the popular belief, that the putrescence of a dead body, or the filth of any sort of decayed matter engenders worms; and being desirous of tracing the truth in the case, I made the following experiment:

"At the beginning of June, I ordered to be killed three snakes, the kind called eels of Aesculapius. As soon as they were dead, I placed them in an open box to decay. Not long afterwards I saw that they were covered with worms of a conical shape and apparently without legs. These worms were intent on devouring the

meat, increasing meanwhile in size, and from day to day I observed that they likewise increased in number; but, although of the same shape, differed in size, having been born on different days. But all, little and big, after having consumed the meat, leaving only the bones intact, escaped from a small aperture in the closed box, and I was unable to discover their hiding place. Being curious, therefore, to know their fate, I again prepared three of the same snakes, which in three days were covered with small worms. These increased daily in number and size, remaining alike in form, though not in color. Of these, the largest were white outside, and the smallest ones, pink. When the meat was all consumed, the worms eagerly sought an exit, but I had closed every aperture. On the nineteenth day of the same month some of the worms ceased all movements, as if they were asleep, and appeared to shrink and gradually to assume a shape like an egg. On the twentieth day all the worms had assumed the egg shape, and had taken on a golden-white color, turning red, which in some darkened, becoming almost black. At this point the red, as well as the black ones, changed from soft to hard, resembling somewhat those chrysalides formed by caterpillars, silkworms, and similar insects.

"My curiosity being thus aroused, I noticed that there was some difference in shape between the red and black eggs (*pupae*), though it was clear that all were formed alike of many rings joined together; nevertheless, these rings were more sharply outlined, and more apparent in the black than in the red, which last were almost smooth and without a slight depression at one end, like that in a lemon picked from its stalk, which further distinguished the black egglike balls. I placed these balls separately in glass vessels, well covered with paper, and at the end of eight days, every shell of the red balls was broken, and from each came forth a fly of gray color, torpid and dull, misshapen as if half finished, with closed wings; but after a few minutes they commenced to unfold and to expand in exact proportion to the tiny body, which also in the meantime had acquired symmetry in all its parts. Then the whole creature, as if made anew, having lost its gray color, took on a most brilliant and vivid green; and the whole body had expanded and grown so that it seemed incredible

that it should ever have been contained in the small shell. Though the red eggs (*pupae*) brought forth green flies at the end of eight days, the black ones labored fourteen days to produce certain large black flies striped with white, having a hairy abdomen, of the kind that we see daily buzzing about butchers' stalls. These at birth were misshapen and inactive with closed wings, like the green ones mentioned above.

"Not all the black eggs (*pupae*) hatched after fourteen days; on the contrary a large part of them delayed until the twenty-first day, at which time there came out some curious flies, quite distinct from the other two broods in size and form, and never before described, to my knowledge, by any historian, for they are much smaller than the ordinary house flies. They have two silvery wings, not longer than the body, which is entirely black. The lower abdomen is shiny, with an occasional hair, as shown by the microscope, and resembles in shape that of the winged ants. The two long horns, or antennae (a term used by writers of natural history) protrude from the head; the first four legs do not differ from those of the ordinary fly, but the two posterior ones are much larger and longer than would appear to be suitable for such a small body; and they are scaly, like the legs of the locusta marina; they are of the same color, but brighter, so red, in fact, that they would put cinnabar to shame; being all covered with white spots, they resemble fine enamel work. . . .

ARE WORMS YOUNG FLIES? "I continued similar experiments with the raw and cooked flesh of the ox, the deer, the buffalo, the lion, the tiger, the lamb, the kid, the rabbit; and sometimes with the flesh of ducks, geese, hens, swallows, etc., and finally I experimented with different kinds of fish, such as sword-fish, tuna, eel, sole, etc. In every case, one or other of the above-mentioned kinds of flies were hatched, and sometimes all were found in a single animal. Besides these, there were to be seen many broods of small black flies, some of which were so minute as to be scarcely visible, and almost always I saw that the decaying flesh and the fissures in the boxes where it lay were covered not alone with worms, but with the eggs from which, as I have said, the worms were hatched. These eggs made me think of those deposits dropped by flies on meats, that eventually became worms,

a fact noted by the compilers of the dictionary of our Academy, and also well known to hunters and to butchers, who protect their meats in summer from filth by covering them with white cloths. . . .

THE CONTROL EXPERIMENT. "Having considered these things, I began to believe that all worms found in meat were derived directly from the droppings of flies, and not from the putrefaction of the meat, and I was still more confirmed in this belief by having observed that, before the meat grew wormy, flies had hovered over it, of the same kind as those that later bred in it. Belief would be vain without the confirmation of experiment; hence, in the middle of July, I put a snake, some fish, some eels of the Arno, and a slice of milk-fed veal in four large, wide-mouthed flasks; having well closed and sealed them; I then filled the same number of flasks in the same way, only leaving these open. It was not long before the meat and the fish, in these second vessels, became wormy and flies were seen entering and leaving at will; but in the closed flasks I did not see a worm, though many days had passed since the dead flesh had been put in them. Outside on the paper cover there was now and then a deposit, or a maggot that eagerly sought some crevice by which to enter and obtain nourishment.

"Not content with these experiments, I tried many others at different seasons, using different vessels. In order to leave nothing undone, I even had pieces of meat put under ground, but though buried for weeks, they never bred worms, as was always the case when flies had been allowed to light on the meat. One day a large number of worms, which had bred in some buffalo meat, were killed by my order; having placed part in a closed dish, and part in an open one, nothing appeared in the first dish, but in the second worms had hatched, which changing as usual into egg-shaped balls (*pupae*), finally became flies of the common kind. In the same experiment tried with dead flies, I never saw anything breed in the closed vessel. . . ."⁴⁴

Soon, however, the belief in spontaneous generation received a fresh and vigorous impetus. The Dutchman, Leeuwenhoek, a lens grinder and the janitor of the city hall of Delft, opened the eyes of the world to a new, invisible kingdom. In the year 1683, he discovered, for the first time, bacteria and other microorgan-

isms. Who could doubt the spontaneous generation of these lowliest forms of life that are so simple in their organization? They certainly arose *de novo* from nonliving matter, out of the air and out of the water! To add fuel to the flame, the Irish priest, Needham, announced to the world somewhat later that, in careful experiments, he had actually observed the spontaneous generation of bacteria.

PASTEUR'S EXPERIMENT

About this time, biologists began to take a definite stand in the controversy. Their choice was determined not by actual evidence and observation as we should expect, but rather by their point of view on two theoretical questions in biology. One of these questions was in regard to the nature of the germ cell; the other was in reference to the theory of organic evolution just then coming to the foreground.

Those who held that the egg cell was a miniature organism, a sort of condensed adult which during the time of embryonic development merely grew in size (*preformation*), rejected the idea of spontaneous generation simply because it did not fit into their preconceived notion of the nature of the germ cell. On the other hand, those who claimed the egg to be merely a homogeneous mass of living substance which gradually differentiated into the adult form during development (*epigenesis*), defended spontaneous generation.

Similarly, those biologists who favored organic evolution accepted also spontaneous generation, while those who opposed organic evolution rejected spontaneous generation likewise. For a century, heated debates over the question filled the air. Finally the matter was settled in the only way in which such a question can be settled; namely, by the experimental method.

In the year 1862, the immortal Louis Pasteur settled the question, once and for all, in the negative way. By his classic and brilliant experiments, he demonstrated to a skeptic and for the most part hostile scientific world, that spontaneous generation is a myth, that no life arises unless there is previous life, and that all apparent exceptions are due to the presence of microscopic germs living in great abundance in air and water. Despite his conclusive results, Pasteur met with great opposition. His nega-

tive results did not harmonize with the evolutionary speculations of his time, and, in consequence, his experiments were belittled by many biologists. His enemies accused him of being prejudiced, and insisted that as a faithful Catholic, he could not be unbiased in the matter. Pasteur, however, was not the man to be frightened by such empty accusations. He challenged his opponents, and by even more brilliant experiments demonstrated the correctness of his views in such a decisive manner that all opposition crumbled into the dust. Since then, innumerable experiments have verified his results, and it is a fundamental axiom in biology today that life can come only from previous life: *Omnis cellula ex cellula*.

THE UNIFORMITY OF NATURE

There remains, then, only the other alternative for the origin of life—*creation* of the first life by a Superior Being. This seems logical enough, but here is one case where many biologists are not ready to be logical. Though the one alternative (spontaneous generation) has been proved impossible, most modern biologists are not inclined to concede the other alternative. Here is a peculiar situation. One of the universally recognized laws in the natural sciences is the principle that *we must proceed from the known and actually observable phenomena of the present to a study and understanding of the processes of the past*, for as Lyell, the founder of geology, states it: "The laws of the present are the laws of the past."⁴⁵ The very foundation of exact and experimental science is the *uniformity of nature*, which is the principle that nature's laws have always been and always will be the same. It is the physicists' recognition of this axiom that has made his branch of learning the foremost exact science of our day.

In the case under discussion, the demonstrated and universally recognized law is that life does not arise spontaneously (*de novo*) from lifeless matter. Also, if the laws of the present are the laws of the past, life cannot have originated in the past from lifeless material. There must, however, have been a beginning of life at some time. In fact, we know that the earth at one time was in such a state that life could not possibly have existed. What then is the answer? *Once more there is a parting of the way*. Biologists, who believe that there is more to life than the mere physical

and chemical forces of nature, find no particular difficulty in applying Lyell's principle: "The laws of the present are the laws of the past." To them creation of the first life by a Superior Being is the only alternative. This is well expressed by the German biologist, Reinke: "In my opinion, the first cell can have originated only through an intervention of a cosmic intelligence on the surface of our earth. This intelligence did thereby not at all break nature's laws, but worked with natural forces and directed them, just as a chemist does when he performs a synthesis, a mechanic when he builds a machine."⁴⁶

THE MECHANISTIC THEORY

On the other hand, biologists, who are committed to the *mechanistic theory* of life have to be inconsistent. They have to overlook the fundamental principle of their own science and hold that, in this particular case, the laws of the present were not the laws of the past and that life did originate spontaneously from lifeless materials. In other words, they hold to this theory in spite of all actual evidence of the present to the contrary. The mechanist excuses this inconsistency with two possible explanations. First, he claims that conditions in the past were of such a nature as to have been favorable to spontaneous generation. According to one theory, the earth was once a superheated mass from which organic compounds arose gradually. According to an opposite theory, the gradual cooling of the earth produced the various kinds of chemical combinations, starting with the simple and stable and ending with the complex and unstable; that is, with the organic compounds. Such theories, aside from throwing overboard the uniformity of nature's laws, are not based on observations or known facts, and are therefore mere speculations.

The second excuse of the mechanist is best expressed in the words of the biologist, Naegeli: "The denial of the origin of life by spontaneous generation means the declaration of a miracle."⁴⁷ In other words, since a mechanistic theory of life precludes its origin by a miracle, we must accept its origin by spontaneous generation.

In either solution, however, we really postulate a miracle. If we wish to save the mechanistic theory, we have to turn traitor,

as it were, to our own cause and demand of nature an interruption of her laws—a miracle of our own. If we are consistent and exclude spontaneous generation as the origin of life (because it is a scientific impossibility of the present), we postulate another miracle—the miracle of the creation of life by a Supreme Being.

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⁴⁶J. Reinke, *Die Welt als Tat*, Berlin, 1901. Translation by author.

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CHAPTER XII

BACTERIA AND INFECTION

BACTERIA

Bacteria are extremely minute unicellular plants which are found practically everywhere. They abound in the atmosphere accompanying dust particles, in water, on our bodies, in our clothes, and in our mouths and digestive tracts. In short, bacteria are our constant invisible companions. Certain of them cause such diseases in man as tuberculosis, leprosy, typhoid fever, cholera, lockjaw, diphtheria, and pneumonia. Such disease-producing or pathogenic bacteria are popularly called germs, parasites, or microbes.

Besides engendering diseases in man and animals, bacteria cause great economic loss by destroying food. Thus, unless proper steps, such as refrigeration, smoking, drying, and salting are taken to prevent bacterial action, our butter, eggs, fish, meat, milk, fruit, etc., become inedible and worthless, for bacteria are the causative agents of fermentation, putrefaction, and decay.

"Fermentation" is the term applied to the breaking down of fats, proteins, and carbohydrates into simpler substances through the action of bacteria and other fungi. "Putrefaction" is protein fermentation taking place in the absence of air and accompanied by obnoxious odors. "Decay" is protein fermentation taking place in an abundance of air and without disagreeable odors.

On the other hand, the majority of bacteria are not enemies of man; indeed, many of them are positively useful and indispensable, for many of our physiological activities are dependent upon them. Thus, bacteria convert organic matter into simple salts, such as nitrates and nitrites, which are utilized in rejuvenating worn-out farm land. Other bacteria produce vinegar, and still others give the flavor to butter and the various cheeses. Moreover, certain industries, such as that of tanning, that of curing of tea, that of the manufacture of indigo, as well as that

of the preparation of flax fiber are almost wholly dependent upon bacteria.

Bacteria differ markedly in size and shape. They are the smallest known plant organisms, quite invisible to the naked eye and their presence can be detected only by the use of a microscope. In fact, some of them are so small that many thousands of bacteria can be grouped together before forming a spot large enough to be seen except with high magnification. Of some type of bacteria, it would take from twenty-five to thirty thousand placed end to end to extend the length of a single inch.

The standard of measurement used in microscopy is the micron, a unit equal to the thousandth part of a millimeter or approximately one twenty-five thousandth of an inch. One of the smallest known disease-producing bacteria, the influenza bacillus, is only about 0.5 of a micron in length and 0.2 of a micron in diameter, whereas, the largest bacteria range in size from 30 to 40 microns.

Bacteria are classified according to shapes or forms; namely, the rod-shaped or *bacillus*, the spherical or *coccus*, and the spiral-shaped or *spirillum*. The first two types may exist singly or grouped together in chains or platelike masses (see Fig. 49). Yet, each bacterium which goes to make up the chain or platelike structure is wholly self-sufficient, there being no evidence of a division of labor between the bacteria.

Unlike the animals and higher forms of plants, bacteria have no cell nucleus, but contain chromatin granules which are distributed throughout the cell; these granules correspond to the cell nucleus. Practically all bacteria are surrounded by a gelatinous capsule which is formed from the firm cell wall. It is this gelatinous capsule which holds the bacteria together, after their division, into the chain or platelike masses. Most of us are familiar with the so-called "mother of vinegar" which produces vinegar. It is a gelatinous mass partially filled with bacteria.

Some forms of bacteria are incapable of motion; others move by means of long, vibratory, threadlike structures called "flagella." Certain bacteria have but one of these flagella located at one end; others have two, one at each end; while others again have tufts of flagella at one end, and still others have flagella covering their entire surface.



FIG. 49

Diagram showing the various types of Bacteria. A, various groupings of Coccus forms; 1, in chains (streptococcus); 2, diplococcus; 3, in irregular masses (staphylococcus); 4, in packets (sarcina). B, Bacillus. C, Spirillum.

Reproduction in bacteria is by simple binary fission, a simple transverse partition formed by the coming together of indentations in the outer cell wall so that the bacteria gradually assume an hourglass shape. This division splits the bacterium into approximately two equal parts. The bacillus and spirillum divide at right angles, usually lengthening before division, while the cocci may divide in several planes. Thus, if the cocci divide in one plane only and remain attached, thereby forming chains, they are called "streptococci," while if they divide in two parts,

but remain attached they are called "diplococci." Cocci dividing in two planes, which thus produce irregular masses, are called "staphylococci," while those dividing in three planes, forming packets, are called "saracina" (see Fig. 49).

Cell division is followed by a period of intensely rapid growth; and after each new cell has reached its maximum size, it, in turn, divides. This cycle of division, growth, and subdivision is repeated continually with the most striking rapidity. Indeed, it has been computed that one solitary cholera microbe maintaining its maximum rate of fission for a period of 24 hours would produce 1,600,000,000,000,000 bacteria weighing in the neighborhood of 250 tons. The very vastness of this figure staggers the imagination, but we can form some notion of it by reflecting that it is 110,000 times the number of seconds that have elapsed since the discovery of America. Of course, such an increase does not actually take place in nature. The foregoing figures are based on the supposition that the bacteria are living under ideal conditions; that is, that they are fed the food best suited to their nature and in generous amount, that the optimum quantity of moisture and heat is furnished, and finally, that the waste products, poisons, or toxins, which they form in carrying on their life processes, are removed. Ideal conditions are rarely, if ever, found in nature.

Sometimes the protoplasm of the bacteria breaks up into small masses within the cell wall; these masses are known as "spores." A spore possesses a relatively thick wall which renders it immune to all destructive forces except that of a high degree of temperature or the strongest disinfectants. The apparent object of spore formation is to tide the organism over a period of adverse conditions, such as an inadequate or defective food supply, or an otherwise poor environment. In brief, spore formation enables the organism to survive in an environment not conducive to the active functioning of its life processes, thus securing its persistence until favorable conditions permit it to break forth from its thick-walled case and live normally again.

However, very few bacteria are capable of forming spores. One of the best-known of spore-forming bacteria is the anthrax bacillus which causes anthrax or splenic fever in cattle, occasionally

also in man. It has been estimated that the anthrax spore can live for fifteen days in a 1-per-cent solution of carbolic acid, while the ordinary vegetative form of anthrax dies in two minutes in the same solution. Yet, spores can be killed by the application of intense heat, or better, by placing them for several days continuously in a temperature between 50 and 60 deg. C. This continuous application of heat induces the spores to germinate, and kills the resulting vegetative form. Another method is that of placing the spores in a strong disinfectant,* such as, bichloride of mercury (1 part in 1,000 parts of water), or a 5-per-cent solution of carbolic acid which appears to act directly upon the thick spore case and destroys the life within.

To enumerate the different specific foods upon which bacteria can live would be to attempt the impossible. Nevertheless, bacteria, according to the more generic division of their food supply, can be divided into four general classes.

The first and the largest class live upon dead organic matter, such as meat, butter, urea, feces, and carrion, and are known as "saprophytes." A second class feeds upon the living tissues of plants and animals, such as the disease-producing or pathogenic bacteria which are commonly styled "parasites." The third class resembles the green plants in that they need neither organic nitrogen nor organic carbon, since they are capable of manufacturing their own food out of carbon dioxide and inorganic salts. Lastly, there is the group of bacteria that live wholly in the soil and derive their nourishment exclusively from inorganic substances.

INFECTION

Previous to the understanding of the modes of infection and the mechanism of immunity, medical progress was practically at a standstill. Members of the profession groped aimlessly in vain attempts to combat disease. But with the discovery of the modes of infection and the mechanism of immunity, medicine for the first time approached the status of a real science. Consequently, the study of infection and of immunity has become the corner stone of modern medicine so that to understand and discuss in-

*The difference between a *disinfectant* and an *antiseptic* is that a disinfectant kills bacteria, while an antiseptic merely arrests their growth.

telligently facts told us by our physician concerning ourselves and the methods employed in overcoming illness, it is necessary that all have some definite knowledge about infection and immunity.

When microorganisms enter our bodies, thus causing disease, we are said to have an *infection* or an *infectious disease*; or our bodies are said to be infected. Infection then, is the invasion of the body by microorganisms producing injury and subsequent morbid conditions or symptoms. When larger organisms, such as worms, amoeba, etc., invade our bodies, we have an *infestation*.

The things through which microbes are brought into our bodies are said to be *infective*; e.g., milk (which often contains typhoid germs) and utensils which have come in contact with infectious matter.

TYPES OF INFECTION. Infection restricted to one part of the body is said to be local. Boils and abscesses are familiar types of such local infection. If, however, the agent of infection pushes its way into the blood stream so that it passes throughout the entire body, the infection is said to be general; such a condition is called "septicemia."

It should be kept clearly in mind that not all microbes which enter our bodies are infectious, a fact that should be obvious when we remember that many kinds of microorganisms are normally present in the body. The normal mouth, for example, harbors many pneumococci, the germs which produce pneumonia; and the intestines of even the most healthy individuals contain colon bacilli. Not only will these germs not produce disease, if the body is in good health, thus possessing an adequate resistance, but some of them, such as the colon bacilli, are actually beneficial, for they break down foods into substances which can then be the more readily absorbed by the body.

DIFFERENCES BETWEEN CONTAGIOUS AND INFECTIOUS DISEASES. At this point, it is well to lay emphasis on the distinction between infectious and contagious diseases. As we have already seen, an infectious disease is one caused by the entrance into the body of pathogenic microbes, such as the bacilli of diphtheria, tuberculosis, typhoid, or pneumococci, or the small animals or protozoa which cause malaria, syphilis, sleeping sickness, etc. A contagious disease, on the other hand, is one in which the germ is transmitted

from one person to another merely by contact, as when a well person contracts the disease simply by touching the sick person or coming into close relationship with him. Measles, scarlet fever, smallpox, and chicken pox are familiar examples of contagious diseases.

Since diseases are communicated by bacteria or protozoa, it will be readily seen that all contagious diseases are infectious, but not all infectious diseases are contagious. Thus, for instance, diseases such as lockjaw, pneumonia, cholera, and malaria cannot be transmitted by contact with the sick person, and are therefore not contagious.

CONDITIONS NECESSARY FOR INFECTION. The conditions necessary for infection are usually divided into two groups: Group 1, those relating directly to the microorganisms themselves; Group 2, those relating to the animal bodies which are the objects of attack.

Group 1. In any infection, there must be pathogenic microbes or their toxins within the body, and these microbes must be *virulent*; that is, they must possess the power of multiplying rapidly in the body and of producing severe injury to it. Thus, microbes which multiply most rapidly and produce severe injury are said to have a high degree of virulence, whereas, those incapable of such rapid multiplication and the production of severe injury possess a low degree of virulence. Virulence is not always of the same degree; it may be increased or decreased in many ways.

Increased virulence, in the case of certain microbes, may be produced by successive animal inoculations; e.g., an animal is inoculated with a given microorganism and becomes diseased therefrom. Then from the tissues of this diseased animal, the microorganism is recovered and is injected into another animal of the same kind, and so on. Thus certain strains of diphtheria, after passing through several guinea pigs, will attain a very high degree of virulence for all guinea pigs. On the other hand, a low degree of virulence can be obtained by growing the microorganisms at a high temperature, or in the presence of antiseptics, or lastly by starving them. All living things when grown under unfavorable conditions are naturally weakened. Microbes, when their power of growth and of producing injury is thus lessened or

decreased, are said to have a low degree of virulence, or, to have been "attenuated."

A second factor in infection is *the number of microbes that enter the body*. The exact number necessary for infection is unknown, but there is a certain relationship between the number and the virulence of the microbes. Thus microbes with a low degree of virulence must enter the body in greater numbers than microbes possessing a high degree of virulence.

A third factor is the taking into consideration of *the avenue by which the microbes enter the body*. The path of entrance frequently determines whether or not an infection will take place. Thus, certain types of bacteria can infect only when they enter the body via the alimentary canal. Thus, for example, the typhoid bacillus when taken into the mouth or even when rubbed into the skin causes no injury, but as soon as it has made its way to the walls of the small intestine, and not until then, it can cause infection. Again, the path of entrance may determine the form which an infection may take. If pus-forming bacteria, such as the staphylococci or streptococci, are rubbed into the skin, abscesses or boils occur; if they enter through the blood stream, valvular diseases of the heart result; if their entrance is via the uterus, puerperal fever results; if they enter through the mouth, they cause septic sore throat.

Group 2. The outstanding condition of this group is that *the body must be in a receptive mood*; that is, the body must afford an environment favorable to the growth of the microbes. This means that the tissues or organs preferred by the microbes must be in such a condition that the microbes can actively injure them. A body thus receptive, is said to be "susceptible" to the infection in question.

It is a common observation that, even in the worst epidemics, not all the individuals who are exposed to the disease contract it. Also, that among those who do contract it, some are mildly infected, others severely. The varying severity of cases of infectious diseases may be partly accounted for by differences in the virulence of the attacking microbes, in their numbers, or in the differences in the respective resistance of individuals.

FACTORS TENDING TO INCREASE SUSCEPTIBILITY. By "resistance" is here meant the opposition offered by the body to invading microbes. A vigorous, healthy, active body always possesses sufficient resistance to ward off almost every kind of hostile microbes. However, individuals in apparently excellent physical condition are often attacked, though these are much less likely to be attacked, and even if they are, the infection is generally mild. On the other hand, anything that tends to lower the tone of general health in the body, also tends to lower the general resistance to invading microbes. One may mention a few of the most common of such instances, as exposure to extremes of heat and cold.

Louis Pasteur rendered a naturally resistant hen susceptible to anthrax by chilling it with cold water. Severe hunger and thirst also, lower resistance. Pigeons, which are naturally resistant to anthrax, die if fed insufficient food just before or after the inoculation with anthrax. Generally speaking, then, *the best protection against microorganisms is a vigorous and healthy state of body.*

SYMPTOMS OF INFECTION. After an infection of living tissues has taken place, a definite symptom, popularly known as "inflammation," appears. Inflammation is a physical disturbance characterized by redness, heat, swelling, and pain. These four characteristics are known as "the cardinal symptoms of inflammation." The walls of the blood vessels in the infected area relax, thus slowing up the speed of the blood and, at the same time, affording more space for congestion. This change accounts for the redness and the heat of the infected region. The swelling and pain are caused by the blood rushing through the blood vessels carrying the white blood corpuscles or "leukocytes," and the lymph (fluid part of blood devoid of red corpuscles) to the infected area. This extra amount of lymph and great number of leukocytes entering the infected tissues increase the volume of the tissues and thus, the inflamed portion is swollen. This increased amount of lymph and a great number of leukocytes also exert a pressure on the nerve endings of the infected tissues which accounts for the pain.

The leukocytes are the policemen of the body, whose duty it is to engulf and destroy hostile microbes. The leukocytes push

closely against the microbes and by movements of their protoplasm envelop them completely as an amoeba does its food. The leukocytes then proceed to digest the microbes (see Fig. 6).

The pus which generally accompanies infection is composed of several elements: dead leukocytes, which have been killed in the struggles with the microorganisms, stagnant lymph, the microbes themselves, and broken-down cells of the infected tissues.

MICROBES PRODUCE INJURY MECHANICALLY AND CHEMICALLY

We are now ready to answer the question: How do microbes cause injury? Wherever microbes obtain a foothold, they grow and multiply, and in so doing may block the smaller blood vessels or capillaries, thus causing death to the tissues, because, under such conditions, the tissues can no longer obtain their nourishment from the blood. Injury so produced is called "mechanical injury." Microbes also produce a chemical injury. In the vital processes of the growth and the repair of tissues which have broken down through the expenditure of energy, there are formed waste products or excretions, such as urea, carbon dioxide, and perspiration, which are deadly poisons even to the tissues forming them unless promptly eliminated. So too, microorganisms, during their processes of growth, form waste products known as "toxins," which, when eliminated by the microbes and absorbed by the cells of the body, are the causes of manifold sufferings and diseases.

KINDS OF TOXINS. Toxins are divided into two classes, *exotoxins* and *endotoxins*. To the first class belong those toxins *which diffuse through the cell walls of living microbes into the general circulation*, in those cases where the microbes have infected an animal, or into the culture medium when the microbes are artificially produced. The bacilli of diphtheria and tetanus are quite common, and, at the same time, strikingly typical examples of microbes which form exotoxins.

The tetanus bacillus (generally accompanied by a great deal of foreign matter, since it thrives in street dust, mud, fertilizer, and the feces of man and animals) enters the body through any deep wound, such as a puncture caused by a rusty nail or an injury from firearms, firecrackers, toy pistols, etc. The bacilli

themselves do not leave the wound to enter the blood stream, but their toxins, which have a strong affinity for the nervous system, pass through the cell walls of the bacilli, are readily absorbed by the ends of the motor nerves, and are thus carried to the central nervous system where they cause violent spasms in the muscles of the neck and jaw.

In diphtheria, the bacilli themselves do not enter the blood stream, but thrive on the inner surface of the throat; their toxins, however, pass through the mucous membrane of the throat to enter the blood stream and are thus carried to, and readily absorbed by the tissues, thereby causing a general poisoning of the entire body.

More numerous than the exotoxins, are those of the second class, known as "endotoxins." These latter differ from the former in that, although they form toxins, *such toxins are not liberated until after the death and disintegration of the microbe*, which death and disintegration are presumably caused by the retention of the toxin within the microbe. The toxin, plus the products formed by the death and disintegration of the microbes, is responsible for the resultant malady. Examples of this class are typhoid and colon bacilli, the staphylococci, and the streptococci.

Our reason for stating that it is the toxins, rather than the microbes producing them which are the agents of chemical injury is demonstrated by the fact that, in the case of endotoxins, the symptoms of the disease appear only after the death and disintegration of some of the infecting microbes. In the cases of exotoxins, the following experiment demonstrates what occurs: If microbes which produce exotoxins are grown in an artificial liquid media, and this media is filtered free from the microbes and injected into an animal, the animal exhibits all the symptoms of the disease, just as if it were inoculated with the living microbes.

MICROBES HAVE PREFERENCES. Most microbes and their toxins have a decided preference for certain parts of the body, and unless these parts can be reached by them, the microbes are unable to act and cause disease. Thus, the diphtheria bacillus lodges in the throat, typhoid in the small intestines, pneumococci in the lungs, gonococcus in the genital organs and the outer lining of the eye, meningococcus in the investing membranes of the brain

and spinal cord. The classic experiment of Wassermann and Takaki shows the specificity of the tetanus toxin. They showed that, if brain tissue is placed in a solution of tetanus toxin and then removed, the remaining fluid will be found free from poisonous effects, for the tetanus toxin will have united with the brain tissues, thus showing its great affinity for it. It is possible to inject a mixture of brain tissue and tetanus toxin into an animal without producing any toxic effect, which demonstrates that its attraction for nervous tissue is so strong as to establish a stable compound.

SPECIFICITY OF MICROBES. *Microorganisms are specific in their activities*, that is, they are separate and distinct entities and each produces (pus-forming microbes excluded) one specific disease and one alone. Thus, the Klebs-Löffler's bacillus produces diphtheria, while the bacillus of Eberth produces typhoid fever. Moreover, the diphtheria bacillus, whether found in the body or in culture media, remains the diphtheria bacillus and does not tend toward the tubercular bacillus or the tetanus bacillus. This specificity of microorganisms is of utmost importance in the treatment of diseases.

To prove that a certain germ is the cause of a specific disease, it is necessary, (1) that the particular bacteria, and this one only, be constantly found in the disease; (2) that these bacteria, when isolated in a pure culture apart from all pathological material, be capable of developing more bacteria, which in turn, when inoculated into suitable animals, will reproduce the same disease. And it is further necessary that such cultured bacteria shall be capable of a second inoculation in pure culture, and so on indefinitely. This method of determining whether or not a certain microbe is the cause of a specific disease is known as "Koch's Circuit."

From what has been said in the foregoing, it might appear that the body is utterly at the mercy of hostile microbes, but, fortunately, such is not the case. A healthy body possesses ample means of defense, both external and internal, against microbic invasion. The external defenses consist: (1) of an *unbroken skin* which is the foremost external means of protection; (2) of *healthy and unimpaired mucous membranes*. The importance of healthy mu-

cous membranes is well illustrated by the frequency with which attacks of diphtheria and measles, which injure mucous membranes, form the starting points of other serious infections. And (3) of *certain secretions*, such, for example, as saliva and the product of the lacrimal glands both of which are slightly germicidal, and the gastric juice which has quite strong germicidal powers. Lastly, the eyelashes and eyelids also act as means of protection, inasmuch as they keep out minute particles which may be germ bearers.

The internal defenses of the body will be spoken of in the following chapter.

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CHAPTER XIII

IMMUNITY

Every living thing, from the lowliest one-cell animalcules to the lumbering giants of the tropics and the leviathans of the waters, is the object of attack by an army of pathogenic microbes which abound everywhere and are the deadliest foe of other living organisms. Let us remember that every infectious disease is nothing but a struggle between the thing infected and the infecting organisms. Against these microscopic vandals, nature has provided all living things with adequate means of defense, which, when rightly disposed and properly employed, constitute a resistance sufficiently strong to overcome even the severest of microbic invasions. That the body possesses defensive powers which resist the injurious actions of microörganisms and their toxins is well established by the fact that men and the lower animals do recover from infections. The resistance afforded the body by its defensive powers is termed "immunity."

IMMUNITY IS RELATIVE

It should be borne in mind from the very beginning that immunity to disease is nearly always relative; it is rarely, if ever, absolute. Thus, we have already seen that, during an epidemic, not all those exposed to the disease, contract it, and that, among those who do contract it, some are only mildly affected and easily recover, while others are severely attacked and, in many cases, do not recover. These facts in part are accounted for by the varying degrees of resistance possessed by different individuals. For example, during the severe visitation of the influenza in the fall of 1918, mortality in our army training camps was excessive, yet there were vast numbers of recoveries and numerous instances where soldiers were not attacked at all. As the recruits were nearly all of the same age and the physical and other attendant circumstances and environment were perhaps more

nearly identical than is usually the case, this marked difference in the violence of the plague must be set down chiefly to *varying degrees of resistance of the individual soldiers*.

VARIATION OF IMMUNITY AMONG MEN AND THE LOWER ANIMALS

Among the various races of men, variations in resistance to certain diseases are also observed. The less highly civilized races such as the American Indian and the Negro are much more susceptible to tuberculosis than the White Man, apparently because the White Man has fought the disease for centuries and has thus developed a comparative immunity to it, while on the contrary, the Indian and Negro never having had the disease until it was brought to them by the White Man, are likely to succumb quickly. On the other hand, the Negro has greater resistance to certain tropical fevers, such as malaria, than has the White Man. Such resistance or immunity as is found among the various races is known as "racial immunity." However, it should be remembered that there is no race of men which is absolutely immune from any human disease. And moreover, what is called "racial immunity" is not as pronounced as it was once thought to be, and may, in all probability, be due to external conditions, such as variations in infections, difference in hygienic conditions, and customs, etc., rather than to any innate racial differences.

Again, among various species of animals, variation in resistance to disease is readily observed. The white mouse is a good example. It has very little resistance to glanders; that is, it is quite susceptible to this disease, while the field mouse is immune. Ordinary sheep are very susceptible to anthrax, while the Algerian sheep are immune. The dog, too, possesses a marked resistance to the anthrax bacillus. The hen and frog are resistant to tetanus. The immunity of these animals is, however, only relative, since it is possible to produce artificially these particular diseases in them. For instance, if a frog is kept in a warm place and inoculated with tetanus bacilli it shows symptoms of infection. In any case, however, their susceptibility to these diseases is much less than man's.

Naturally, owing to the great gulf separating man from the lower animals, we find greater resistance on the part of man to diseases peculiar to the lower animals, and vice versa; indeed we

find very few diseases common to man and the lower animals, even when they live in the closest conjunction and under apparently identical conditions. Leprosy, diphtheria, gonorrhea, syphilis, and typhoid fevers are examples of the more serious diseases, while mumps, measles, chicken pox may be thought of as among the less serious diseases to which human beings are everywhere prone and to which lower animals are more or less exempt. Such diseases as chicken cholera, hog cholera, and swine erysipelas are epidemic among animals, while man is exempt, even though he work constantly with animals so infected.

NATURAL IMMUNITY

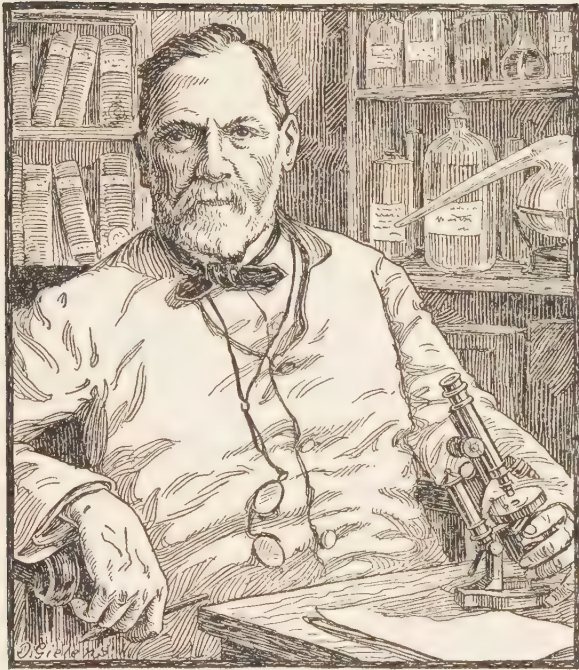
The resistance or immunity to certain diseases possessed from birth by some individuals, families, races, and species is called "natural immunity" and may be subdivided into "racial" or "familial" immunity according to the classification of those possessing it. Natural immunity, then, is that power or condition, existing from birth, in an individual, which protects that individual from contracting a certain disease. Thus, the goat is naturally immune to tuberculosis, the chicken and frog to tetanus, and the dog to anthrax.

ACQUIRED IMMUNITY

Immunity developed after birth is called "acquired immunity." Acquired immunity may be developed in two ways, naturally or artificially. From time immemorial, men have noticed that, in the case of certain diseases, one attack rendered the individual immune for the remainder of his existence; thus an attack of measles in childhood usually renders us immune to that disease throughout life. Attacks of scarlet fever, mumps, and yellow fever likewise render the average individual permanently immune. This acquired immunity which has developed normally from an attack of a disease is called "naturally acquired immunity."

Progress in science has taught us that immunity may be brought about by laboratory means; this is called "artificially acquired immunity" and is further said to be actively acquired or passively acquired.

Artificially acquired active immunity is obtained by injecting either dead bacteria into an individual, as in the case of typhoid



LOUIS PASTEUR (1822-1895)

"The most perfect man who ever entered the kingdom of science."—Sir William Osler.

"It was given to him in a specially high degree to make the results of his investigations of practical use to mankind; whether it was a question of inventing a method of preserving food, combating the diseases of domestic animals, or treating rabies, which had hitherto been considered incurable. This last-mentioned discovery made him particularly popular. Through an international fund there was founded in 1889 an institute for the purpose of investigating those fields of research to which he had devoted himself, which bore his name, and to the management of which he afterwards devoted all his energies. Previously pupils had already flocked to his laboratory from all parts of the world; many of them have themselves won great fame. Nevertheless, his brilliant career had certainly not been entirely free from shadows. In his political views Pasteur was a conservative and a warm partisan of the French Empire, and moreover a strictly faithful Catholic. This caused him a great deal of unpleasantness, owing to radical opposition, producing an atmosphere that is even reflected in the scientific polemics against him."—Erik Nordenskiöld, *The History of Biology*, Alfred A. Knopf, 1928.

vaccination, or living bacteria of diminished virulence, as in the treatment of hydrophobia. This latter method also was formerly used in smallpox vaccination by inoculating individuals with the dried pus from the sores of infected persons, a method of immunizing against smallpox introduced into England from the Orient by Lady Mary Wortley Montague during the eighteenth century. In the Orient, it was the custom to tear open several veins with a needle and to place as much dried pus in each vein as could be carried upon the point of a needle.

In 1770, Edward Jenner, an English physician, who had been long studying the development of cowpox and swine pox which had been transmitted to man, first proposed his theory that an attack of cowpox, if induced in a human subject, would prevent smallpox. He had often observed two striking facts: (1) that there was a genuine resemblance between the sores found upon the udders of cows and upon the hands of milkmaids suffering from cowpox; and (2) the fact that milkmaids so infected were generally immune to smallpox. Jenner, thereupon, inoculated his own son with cowpox and later inoculated him with smallpox, finding him absolutely immune to the latter. In 1796 he gave a public demonstration by inoculating another subject in the same way and with the same results. Although, at that time Jenner's theory and practice met with violent opposition and even persecution, it later became the accepted method of smallpox prevention.

Not until the time of Louis Pasteur (1822-1895) was further progress made in inducing artificial immunity. Pasteur, a French chemist and the founder of the science of bacteriology, conceived the idea of protecting individuals against disease by artificially inducing a mild attack through inoculations with artificially weakened bacteria. In this way he was able to secure protection against chicken pox, cholera, anthrax, and hydrophobia. He had observed that a hen would become only slightly ill and ultimately fully recover if inoculated with cholera germs that had been weakened by cultivating them for a long period of time on artificial culture media. Then he noticed that a hen so treated could be later inoculated with a fatal dose of virulent cholera germs without any infection whatever. Therefore, an immunity de-

veloped by inoculating an animal with microörganisms of modified form is called "artificially acquired *active* immunity." It is *artificial*, because the microbes were placed in the hen by a hypodermic needle which is not the natural means of entrance of bacteria, and *active*, because the tissues of the hen took an active part in the production of the protective substances.

"Artificially acquired *passive* immunity" is brought about when the blood serum of an individual, which has been actively immunized against a certain disease, is injected into a second individual. The tissues of the second and passively immunized individual take no part in the production of the protective substances which have already been formed in the body of another.

The best example to illustrate artificially acquired passive immunity is that brought about by the injection of diphtheria antitoxin into human beings. A brief description of the preparation of this antitoxin may make this variety of immunity clearer. In 1880, von Behring and Kitasato discovered that rabbits which had been actively immunized against diphtheria by an inoculation with weakened diphtheria bacilli were subsequently enabled to withstand inoculations with virulent bacilli sufficient to produce death ordinarily. Hence, they inferred that the blood serum of these rabbits contained something capable of neutralizing diphtheria toxins. The animal now used in the preparation of diphtheria antitoxin is the horse, for it was found that, because of its size and endurance to treatment with diphtheria toxin, the horse was the better animal.

The diphtheria germs are grown in flasks of bouillon. This bouillon is filtered free of the germs and a very small amount of this filtrate (which contains the diphtheria toxin) is injected into a horse. At intervals of five to seven days, for a period of two or three months, the horse is given gradually increasing quantities of diphtheria toxin. The first inoculation makes the animal slightly ill, but he quickly recovers. The subsequent inoculations, though increased in amount, have no effect. The last inoculation given is, under normal circumstances, sufficient to kill any untreated horse. Thus, the horse has been actively immunized against diphtheria, and at the end of two or three months, five to eight quarts of blood may be taken from him at one time.

The substances which protected the horse against diphtheria are in its blood. Because this blood serum contains protective substances it is called "antitoxin" (against the toxin). Antitoxic serum, in appearance, does not differ from the blood serum of an untreated animal. Even when chemically tested the differences noted are extremely slight. To determine the presence and also the strength of antitoxin in a serum, it is necessary that some of the antitoxin be injected into an animal which has already been inoculated with diphtheria toxin. The animal used for this purpose is the guinea pig which, because of its almost universal use in bacteriological work, has been aptly called the Cinderella of the bacteriologist. The smallest amount of antitoxin which will neutralize 100 times the fatal dose of toxin for a guinea pig weighing 250 grams is called the "antitoxin unit." Thus, the statement that "the adult in severe toxic cases of diphtheria should be given 20,000 units of diphtheria antitoxin" means that the sufferer is to be inoculated with as much of the antitoxin as would be necessary to save 20,000 guinea pigs, each weighing 250 grams, though each had received 100 times the fatal dose of diphtheria toxin. The amount of diphtheria toxin which constitutes a fatal dose depends, of course, upon the virulence of the culture. Some cultures are so virulent that $\frac{1}{500}$ c.c. of their toxin is sufficient to produce death in a 250-gram guinea pig.

IMMUNITY IS SPECIFIC

Acquired immunity, whether resulting from a natural attack of the disease or from an inoculation of dead or living bacteria which have been attenuated, is *always specific*. Thus, smallpox vaccination protects against smallpox only, not against measles; an attack of diphtheria protects against diphtheria and not against some other disease.

There is considerable variation in the period of protection following acquired immunity. Thus, one attack of typhoid fever, smallpox, scarlet fever, or mumps renders the individual immune for life; while pneumonia, influenza, gonorrhea, diphtheria, tuberculosis, malaria, and tetanus confer only temporary immunity. The duration of the protective period conferred by active immunization in smallpox vaccination varies greatly with the individual. It is definitely known that, as a rule, the protective period

is only a few years, consequently, in case of a smallpox epidemic, it is imperative that everyone who has been at all exposed to the disease should be vaccinated again. Passive immunity confers the briefest period of protection. For instance, diphtheria antitoxin confers immunity for a period no longer than twenty-eight days, tetanus antitoxin for about twelve days. On this account, during the late war, wounded men were given inoculation with tetanus antitoxin about every nine days.

The *efficacy of vaccines* (dead or attenuated microbes used for preventive inoculation against a disease) now available against smallpox, hydrophobia, anthrax, typhoid fever, cholera, and plague, and the *sera* used in the prevention and treatment of tetanus, diphtheria, tuberculosis, and meningitis is quite manifest. One need but observe the comparative innocuousness of these diseases today, as compared with their violence of but a few years ago.

INTERNAL DEFENSES OF THE BODY

Up to this point, we have merely called attention to the fact that the body possesses certain means which it can rally in an effort to combat and overcome microbic invasion. Let us now attempt to examine the nature of these protective substances or *antibodies* which the body manufactures.

It is an established fact that the normal blood can not only neutralize bacterial toxins, but that it can also destroy bacteria themselves. For the destruction of the microbes, the body forms *antibodies*, whereas, for the neutralization of their toxins, it manufactures *antitoxins*. In contrast to antibodies we have the term *antigen* to designate any foreign substance which leads to the formation of antibodies. Such substances are not only the hostile microbes, but even such harmless objects as milk or other nourishment introduced not as a product of digestion, but in its natural form as an injection into the blood.

We are already familiar with the fact that there are two kinds of bacterial poisons, *exotoxins* which are secreted by the bacteria and which circulate in the blood stream, while the bacteria themselves remain in their place of lodgment, and *endotoxins* which are released only after the death and disintegration of the bacteria, which were circulating in the blood stream.

Against endotoxic bacteria the body forms the following antibodies:

Agglutinins are substances which cause motile microbes to lose their motility and gradually to collect into clumps. In the strict sense, agglutinins are not antibodies, for, clumping together does not destroy the microbes, but we mention them under this heading because the phenomenon of clumping is of vast importance in the diagnosis of certain diseases. Agglutination is so specific that the serum of an individual suffering from typhoid fever will cause the clumping together of typhoid bacilli when but a few drops of it are placed in a culture of typhoid germs.

Bacteriolysins are substances which actually kill and destroy bacteria. Thus, if typhoid bacilli are injected into an animal, the serum will, after a time, kill off enormous numbers of them. This fact is demonstrated by taking some serum, mixing it with typhoid bacilli and, after an interval, examining it under a microscope when it will be seen that the bacilli have actually dissolved.

Precipitins are substances which produce precipitates in bacterial cultures that have already had the bacteria filtered out. Like agglutinins, these are not antibodies, but because they are formed during microbic invasion and because of their importance in medico-legal investigations, it is well to consider them under this head. If a small amount of human blood is injected into an animal and afterwards some of the resultant serum is mixed with human blood, a precipitate is formed. Such a precipitate is formed, however, *only when the serum of the treated animal is mixed with human blood*; it forms no precipitate with the blood of any other animal. In this way, human bloodstains are distinguished from other bloodstains, a fact which has been often utilized in recent years in criminal trials.

Opsonins are substances which act upon the microbes in such a way as to facilitate their being engulfed by the white corpuscles or leukocytes.

Antibodies are always found in the blood serum. In this connection, it is well to recall the distinction made between blood serum strictly so called, and the blood plasma. Blood serum is the fluid part of the blood which remains after the clot has been formed. Thus, when we cut ourselves the whole blood which

comes forth is fluid, in a few moments, however, it becomes viscid or sticky; then it becomes firm and gradually shrinks, finally pressing out a clear straw-colored liquid which is the blood serum. It will thus be seen that *blood serum exists only in blood outside the living body*. On the other hand, the fluid part of living blood, that is, blood within the living body, is properly called "blood plasma." Though this blood plasma contains antibodies, no means have as yet been devised to detect their presence in it. Even in the case of blood which has been shed, no trace of antibodies can be found if the blood is prevented from clotting either by beating it vigorously for a few minutes or by adding to it some chemical, such as potassium citrate. Only in blood which has been allowed to clot and form the straw-colored blood serum can antibodies be found.

The power of the blood to destroy microorganisms varies with different individuals; thus the blood of an individual who has been immunized against any disease possesses greater bactericidal power than the blood of one not thus immunized.

THEORIES OF IMMUNITY

Two theories have been advanced to explain the phenomena of immunity. The one, Ehrlich's Receptor or Humoral Theory, asserts that the body fluids are the chief factors in immunity; the other, Metchnikoff's Theory of Phagocytosis, holds that the white corpuscles are the prime factors in immunity.

We know that a magnet attracts iron filings, and that certain chemicals have affinities for each other, such as hydrogen has for oxygen. It appears that every cell of the body also, because of certain molecules connected with it, has affinities for certain substances, and this assumption forms the basis of the explanation of immunity. As the blood courses through the body, cells with which it comes in contact exert their affinities for the substances carried by the blood. This power of extracting these substances is located in molecules called "cell receptors." To form some idea of the cell receptor, as postulated by Ehrlich's theory, we need but visualize the burr of the horse chestnut. Anyone, who has attempted to pick up one, knows well that the whole surface is covered with sharp projecting points or prickles. In our exam-

ple, the body of the burr corresponds to the cell, and the prickles to the cell receptors. (See Fig. 50.) The receptors have the power of anchoring to themselves whatever toxin in the blood for which they may have an affinity. When a receptor has an-

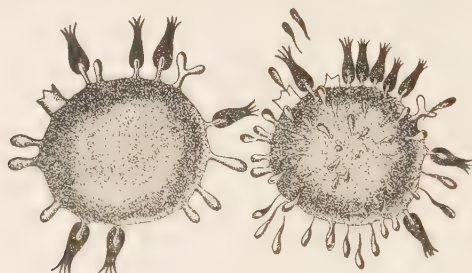


FIG. 50

The left-hand figure shows a cell embarrassed by the attachment of haptophorous groups; the right-hand figure a cell compensating by regeneration of the receptors, some of which can be seen detaching into the surrounding tissue juice.

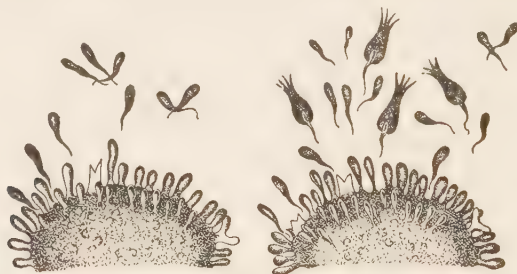


FIG. 51

The cell on the left hand, having regenerated great numbers of receptors for which there is no immediate use, detaches them into the tissue juice or blood; on the right hand these same detached receptors meet haptophores in the blood, with which they combine, thus preventing these elements from reaching the cells. The combination shown corresponds with the toxin-antitoxin combination, and may take place as well in *in vitro* as in the body of an animal. (Redrawn from *Biology, General and Medical*, published by W. B. Saunders Co.)

chored to itself a poison there is damage to the cell itself as well as the loss of a receptor. The cell then attempts to compensate for its loss by forming receptors in excess of its actual needs. One often sees this principle of compensation in action in living things. Thus when one cuts himself, a scar forms which is slightly elevated. Such an elevation means merely that more tissue has been formed than there was skin before.

Where a cell causes many receptors to form, some of these separate from the cell and pass off into the blood stream as "free receptors." (See Fig. 51.) These retain their power of anchoring toxins just as efficiently as they did when attached to the cell from which they arose. The free receptors then, are the antibodies, the antitoxins, the agglutinins, the bacteriolysins, etc. Thus diphtheria antitoxin, which is made of the blood serum of a horse containing a vast number of free receptors, is the principle of active immunity in the horse himself, but of passive immunity in the human subject into whom it is injected.

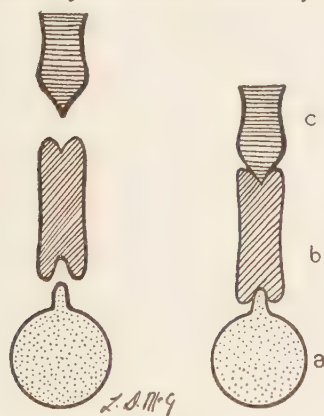


FIG. 52

Diagram illustrating factors concerned in Immunity. a, Cell or Antigen to be dissolved; c, the Complement or Solvent by which it is dissolved; b, the Amboceptor or Intermediate Body by which the two can be brought together.

the toxin is again possible. Therefore, it is evident that the receptor needs the complement before it can unite with the toxin, and for this reason, the receptor is called the "amboceptor." In a word, the amboceptor is a joint principle, composed of the receptor and complement, which is the active immunizing force of the blood. (See Fig. 52.)

Natural immunity, according to this theory, differs from all forms of acquired immunity, natural or artificial, active or passive, in that bacteria or their toxins entering a body, find

Before these cell receptors can anchor poisons to themselves, certain conditions must be fulfilled. The condition, which is of importance here, is that a fermentlike substance, called the "complement," must be present. The existence of such a substance can be demonstrated in the laboratory. In blood serum which has been heated for an hour at 55 degrees Centigrade, no union is possible between the receptor and the toxin. Whatever it is that effects the union and which is apparently destroyed by the heating process, is called the "complement."

If, however, some unheated blood serum is afterwards added, the union between the receptor and the

therein no cells having an affinity for them. No receptors are consequently formed, nor are antibodies or antitoxins. Thus, an animal possessed of natural immunity to a given disease (as the dog to anthrax) is incapable of suffering from infection from the germs of that disease, or of furnishing a blood serum which can be used in protecting others against that disease. In other words, natural immunity is a negative thing; acquired immunity, whether naturally or artificially acquired, is something positive.

THE WHITE CORPUSCLES AS BODY DEFENSE

Besides antibodies, organisms have another means of defense; namely, the white corpuscles or leukocytes. The leukocytes have amoeboid qualities, which qualities are responsible for the power the leukocytes have to surround and destroy microbes which enter the body. This process of microbic destruction is called "phagocytosis" and constitutes one of the most important safeguards which the body has against microbic invasion. The leukocytes are able to attach themselves to the walls of the blood vessels and to perforate them in order to gain access to the deeper tissues. Thus, if microbes succeed in reaching the deeper tissues, the leukocytes leave the blood stream and proceed to the infected spot and there enter into combat with the microbes, attempting to engulf and digest them.

In some diseases, such as pneumonia, the number of leukocytes is increased from the normal 9,000 per cubic millimeter of blood to 17,000 and 20,000; while in other diseases the number may decrease. Thus the importance of the "blood count" in medicine is apparent.

The process of phagocytosis consists of three steps: (1) the coming together of microbes and leukocytes, (2) the engulfing of the microbes by the leukocytes, and (3) the digestion of the microbes by the leukocytes. The success of phagocytosis is, in a great measure, dependent upon the opsonins mentioned in the foregoing.

It is interesting to note that neither the cell receptors nor the leukocytes are of themselves capable of efficient action, the leukocytes are dependent upon the opsonins and the free receptors are dependent upon the complement.

In organisms naturally immune to certain diseases, the leukocytes engulf and destroy the microbes readily, because there are no body cells which have an affinity for the microbes or their toxins. Hence the microbes or their toxins can produce no harm, and the leukocytes are free to attack the invading microbes. This is well exemplified in dogs which are naturally immune to anthrax. If anthrax bacilli are injected, the white corpuscles readily engulf them.

In attempting, therefore, to explain immunity fully, it is necessary to consider both Ehrlich's Receptor Theory and Metchnikoff's Theory of Phagocytosis, for the destruction of microorganisms in immune animals is effected in two ways: (1) by the germicidal body fluids, such as the blood, and (2) by the activity of the leukocytes.

THE PHENOMENON OF ANAPHYLAXIS

Before concluding this chapter, there is one more phenomenon which must be mentioned, that of *anaphylaxis*. The word *anaphylaxis* means *against protection*; it is the opposite of *prophylaxis* which means *for protection*. The name is applied to those organisms which show extreme sensitiveness to certain microbes and certain proteins. Thus, a guinea pig may be made sensitive to such harmless protein as that contained in ordinary milk. When milk or other proteins are taken naturally, that is, through the mouth, and from there to the stomach and intestines, they are acted upon by certain ferments which break them up so that they can be used as food for the body. When, however, these substances are taken into the body by way of the blood stream, that is, intravenously (injection into a vein), or by way of the muscles, that is, intramuscularly (injection into the muscles), by hypodermic injections, antibodies are formed, and these antibodies may give rise to serious symptoms or they may even produce death. As a rule, the first injection causes no distress, but a second injection may be fatal. This explains why in some individuals a mere inoculation, as for instance, of diphtheria antitoxin may produce a severe shock which sometimes proves fatal.

The principle of anaphylaxis is of great importance in the diagnosing of certain diseases. If a person who is extremely sensi-

tive to a certain infection because he is infected with it, is injected with a specific microbe or toxin, a shock to the nervous system results; this is called an "anaphylactic shock." Although the shock is generally not sufficient to overcome the individual completely, it does produce marked reaction. Thus, if a person suffering from tuberculosis is injected with tubercular bacilli or tuberculin, a fall in temperature and a slight fever will result. In fact, this is the well-known tuberculin test applied to both men and cattle for the purpose of detecting the presence of tuberculosis. The so-called Schick test is also based upon this principle of anaphylaxis, a test used in determining whether or not a person is susceptible to diphtheria. So, too, the determination of the specific pollen which causes hay fever in an individual is based upon the same principle of anaphylaxis. The hay-fever sufferer is inoculated with various types of pollen, and when the particular type to which the individual is sensitive has been injected, a white elevation appears on the spot where the needle was applied.

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CHAPTER XIV

VERTEBRATE ORGANIZATION

We have already seen that the fundamental, essential substance of all living things is protoplasm, a substance which is not structureless, but is divided into many small units called "cells." These cells, though separate and individual in themselves, are, nevertheless, not isolated, but are coördinated as a whole both structurally (anatomically) and functionally (physiologically). When groups or aggregations of similarly constructed cells perform a particular function, they are said to constitute a "tissue," and aggregations of tissues which perform a particular function are in turn called "organs." It will be remembered that bacteria and other one-cell plants, as well as one-cell animals, have all the necessary structural material within them to perform the necessary functions to keep them alive and to permit them to reproduce, and they are thus true organisms. All higher organisms, hence, possess organs which work in harmony with each other for the maintenance of the whole called an "organism." The term "organism" is used only in speaking of living things.

Organisms are classified variously. One fundamental classification is that of *vertebrate* and *invertebrate*. All animals possessing a backbone (composed of separate pieces called vertebrae) are vertebrates, while animals not possessing a backbone are invertebrates.

In an earlier chapter we learned that all living things or organisms differ from nonliving or lifeless things in three fundamental respects: (1) all organisms manufacture their own protoplasm (metabolism); (2) they respond to internal and external stimuli (irritability); (3) they propagate themselves (reproductivity).

Our purpose now is to study the various systems (a system is a group of organs performing a specific function) of a vertebrate organism both structurally and functionally, and by so doing to learn how the vertebrate organism performs the three essential

processes which distinguish it from lifeless matter. The particular vertebrate organism which we shall study is the human body.

THE HUMAN BODY

Everyone has frequently observed how coal burns. When coal, an organic material, unites with oxygen, it burns (oxidation), and in so doing releases energy in the form of light and heat. In this process, the coal is broken up into simpler substances—carbon dioxide, water, smoke, and ashes. The same thing that happens when coal releases its energy also happens when living bodies release it. All activity in living bodies, whether plant or animal, is attended by oxidation; i.e., by the union of oxygen with the plant or animal tissue. And, as in the oxidation of coal there are formed water, carbon dioxide, and ashes, so in the oxidation of living protoplasm, water and carbon dioxide are formed, while in place of ashes there is formed a like useless residue, urea.

If a steam engine is to be kept moving, the combustible material, its food; i.e., the fuel which by its burning releases the energy, must be constantly renewed and the waste products formed must be removed. So it is in the case of living things, the protoplasm which breaks down when energy is released by oxidation must be renewed or repaired and the waste products formed must be removed, if the organism is to continue living or releasing energy.

METABOLISM

Since animals cannot of themselves produce the material from which protoplasm, broken down by the releasing of energy, can be repaired, they must obtain such materials from their environment. Such materials, which the body can convert into protoplasm, and from which energy can be derived are called "food." Food, however, before it can be made into protoplasm, has to undergo certain changes, while the protoplasm, also undergoes a transformation in releasing energy. The sum total of the changes which the food undergoes in the body until it is ready to pass into the blood is called "digestion." The changes in the cell protoplasm involved in the assimilation of this prepared food and the rejection of their own worn-out elements is called "metabolism," which latter term may be defined as, the chemical changes which are continu-

ally taking place in living cells by which energy is provided for the vital processes and food is assimilated to repair waste. It is clear, therefore, that metabolism is a *dual* process, (1) a building up, and (2) a breaking down.' The former process is called "anabolism" and the latter "katabolism."

Food. Food, in the concrete, is any substance which, when assimilated by a living thing, either supplies it with energy or builds up its protoplasmic substance. Most foods are not simple substances or, in other words, are not single chemical entities, but are complex substances composed of many chemical entities called "foodstuffs." Foodstuffs are usually classified as follows:

ORGANIC	Carbohydrates	{ Sugars, starches, etc. These substances contain carbon, hydrogen, and oxygen. The hydrogen and oxygen generally exist in the same proportions as they do in water; namely, two parts of hydrogen to one of oxygen.
	Fats	{ Butter, oil, lard, fats. These contain carbon, hydrogen, and oxygen. The oxygen, compared with the carbon, is in less amount than it is in the carbohydrates.
	Proteins	{ Meat, white of egg, cheese, fish, milk. These substances contain nitrogen in addition to carbon, hydrogen, and oxygen. Hence, they are called "nitrogenous substances."
INORGANIC	{ Water and Salts	{ Carbonates Chlorides Phosphates Sulphates } of sodium, calcium, etc.

Foods are of two kinds: foods proper or nutrients, and accessory foods. To the first class belong such as yield energy or build up protoplasm. These are the *organic foodstuffs*. The second class is made up of those substances which yield neither energy nor build protoplasm, but which are necessary and essential for the proper execution of certain vital functions. These are the *inorganic foodstuffs*. Food accessories, such as water, salts, and vitamins, do not need to be digested, since the body can absorb them in the form in which they are ingested. Nutrients, however, must be digested before they can be utilized. Foods, then, since they are not simple, but complex substances, must be reduced to simpler substances before they can be absorbed and it is the purpose of digestion to so reduce them.

We shall now take up the successive steps in the processes of preparing food for the first step in metabolism; namely, *anabolism*. The three steps to consider are: (1) ingestion, (2) digestion, (3) absorption.

INGESTION. Ingestion is the term applied to the taking in and swallowing of any material whatever by a living body, a process confined to animals because plants do not have any "swallowing" organs.

DIGESTION. Digestion takes place in the alimentary canal, a continuous tube extending throughout the entire length of the body. It is suspended in the cavity* formed by the walls of the body. The ingested food passes through a *mechanical* and a *chemical* process; mechanical, by being broken up into small pieces in the process of chewing and by the "churning motion" of the stomach; chemical, by certain acids and alkalis formed in the different parts of the alimentary canal. Such changes are easily demonstrated in a chemical laboratory. Thus if we take a carbohydrate, such as starch, and place it in a test tube and treat it with dilute acids and alkalis at body temperature, the starch, after a long time, will be slowly converted into sugar. If we heat this mixture to a temperature many times higher than the normal temperature of the body, the conversion will be much more rapid. What is done in the laboratory by this high temperature is effected in the living body by certain substances called "enzymes." Enzymes are colloidal chemical compounds, possibly proteins, formed in the bodies of plants and animals to hasten the breaking down or reduction of foods. The importance of the enzymes cannot be overestimated, for there is no single chemical action known in living things in which enzymes are not involved. Digestion, then, is accomplished by bringing food in contact with enzymes in acid and alkaline media, whereupon the food is reduced into simpler substances which can be used by the body.

Enzymes are classified according to the types of foods upon which they act. Thus enzymes which reduce proteins are called

*The cavity which is formed by the walls of the body of man and the higher vertebrates is called the "*body cavity*" or "*coelom*." It is divided into two parts by the *diaphragm*, a muscular membrane stretched transversely across the cavity. The upper part of the coelom, in which are located the heart and lungs, is called the "*thoracic cavity*," while the lower part, which contains all the other organs save the brain, spinal cord, and external genitals, is called the "*abdominal cavity*."

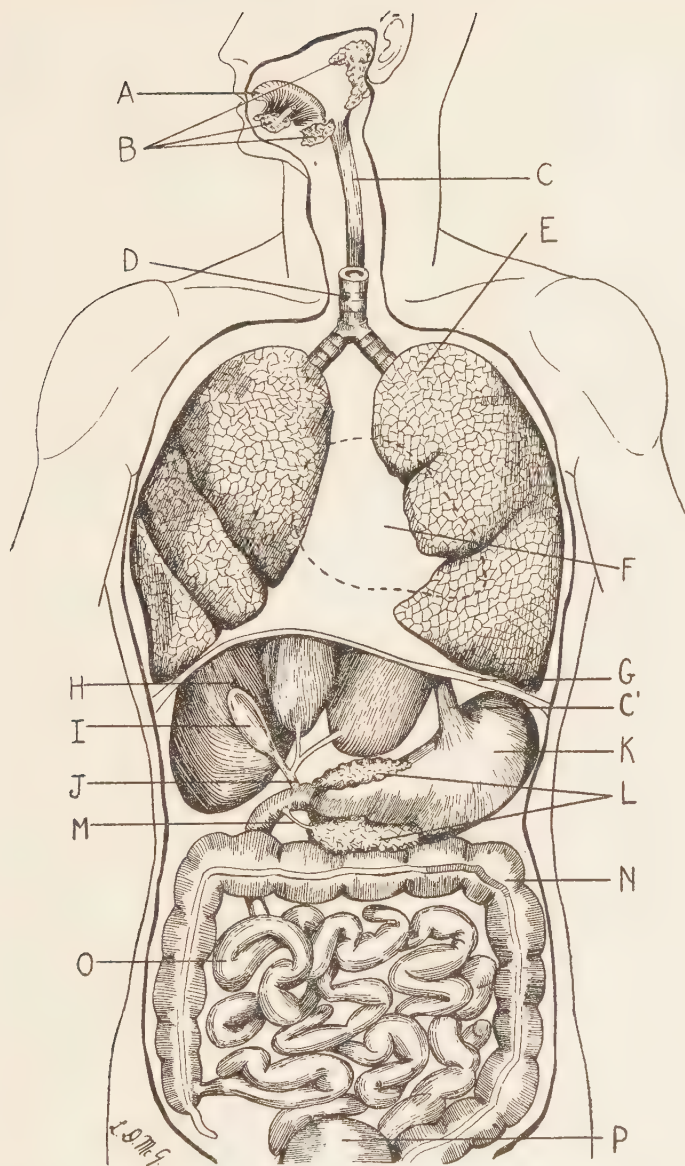


FIG. 53

Diagram showing organs of Respiration and Digestion. A, Tongue; B, Salivary Glands; C-C', Esophagus; D, Trachea; E, Lung; F, Heart; G, Diaphragm; H, Liver (thrown back); I, Gall Bladder; J, Common Bile Duct; K, Stomach; L, Pancreas; M, Pancreatic Duct; N, Large Intestine; O, Small Intestine; P, Bladder; (modified after Gervais).

"proteases"; those which reduce fats are called "lipases"; and those which act upon carbohydrates are called "amylases."

We are now ready to consider the organs of digestion and to study the parts played by each organ in the process.

THE DIGESTIVE SYSTEM

MOUTH. Food is taken into the mouth where it is broken up mechanically by the teeth, into small pieces, a process known as "mastication." (See Fig. 53.) Concomitant with this mechanical action, there is also a chemical one. The food becomes mixed with saliva, an alkaline fluid secreted by the salivary glands and containing 85 per cent water, inorganic salts, mucin (a lubricator) and an enzyme, ptyalin.

There are three pairs of salivary glands*: the *parotids*, which are located in front of the ears; the *sublinguals*, situated below the tongue; and the *submaxillaries*, located under the lower jaw. The enzyme, ptyalin, found in the saliva, converts starch into sugar (maltose). Thus, if we chew a mouthful of bread for several minutes, it becomes sweet because the starch has been changed to sugar. The end product then of mastication is the rounded mass of food which is thoroughly mixed with saliva and in which starches have been changed to sugar.

ESOPHAGUS. When the food is swallowed (deglutition), it passes through the esophagus or gullet, a straight tube about nine inches long, into the stomach where it undergoes further mechanical and chemical action. It may be well to mention, at this point, that the food is carried through the alimentary canal by "peristalsis," a progressive contraction of the muscles in the walls of the alimentary canal, forcing the food along by an undulating contraction and expansion of the longitudinal and circular muscles in the intestinal walls. This continuous contraction and relaxation causes a wavelike motion which propels the food through the alimentary canal.

*A gland is any highly specialized group or mass of cells, so arranged as to form small spherical-shaped cavities, richly supplied with blood vessels. From this abundance of blood, the gland removes substances, wholesome or injurious. Wholesome substances are transformed into complex substances (secretions), which are of use to the organism and are poured into some cavity of the body; for example, saliva into the mouth, gastric juice into the stomach; or on some surface, as the tears; or directly into the blood stream. Other glands remove substances which are of no further use to the body (excretions) and which are injurious to the body if they are not eliminated. Urea, removed by the kidneys, is an example of an excretion.

STOMACH. The stomach is a saclike dilation of the alimentary canal lying in the upper left side of the abdominal cavity, just below the diaphragm. The stomach is composed of four coats of tissue. These, beginning from the inside and going to the outside are: (1) the mucous membrane, so called because it secretes a viscid and colorless fluid called "mucus"; (2) the "submucous" coat, a loose connective-tissue structure containing blood vessels, lymph vessels, and nerves; (3) the "muscular" coat, consisting of three layers, an inner layer running obliquely, a middle layer running circularly, and an outer layer running longitudinally; (4) the "serous" coat, a thin layer of connective tissue, forming the outer coat of the stomach. Muscle layers and membranes similar to those which compose the stomach make up the other parts of the alimentary canal, although in some of them we find slight modifications.

Three parts of the stomach are distinguished by special names (Fig. 53). The rather narrow portion which joins the esophagus and is called the "cardiac" or "esophageal end"; that part which joins with the intestine is called the "pyloric" or "intestinal end," while the large saccular part between the cardiac and pyloric ends is called the "fundus." When the food reaches the stomach, the muscles of the stomach inaugurate a series of peristaltic movements occurring at intervals of about ten seconds which further reduce the food mechanically. Concomitant with the peristaltic movements mentioned in the foregoing, the glands of the stomach, located in the mucous membrane, begin to secrete gastric juice, which further reduces the food chemically. The gastric juice contains water, inorganic salts, two proteolytic enzymes, rennin and pepsin, and about 0.2 per cent of hydrochloric acid.

SECRETION OF GASTRIC JUICE. Merely the sight and smell of food or the presence of food in the stomach will furnish impetus enough to start the glands of the stomach secreting gastric juice, but more important than these is a chemical control of secretion. The presence of meat or meat extracts in the stomach stimulates secretion; hence meat and meat extracts are called "secretogogues." Partially digested bread, white of egg, or starch produce no secretion. It is thought that secretogogues induce the cells lining the pyloric end of the stomach to secrete a substance

called "gastrin" which is taken up by the blood and is carried to all the other cells of the stomach stimulating them to secrete gastric juice. Such a substance as gastrin is called a "hormone." A hormone is a chemical product of a tissue which accelerates activity in an organ by way of the blood stream.

GASTRIC DIGESTION. Pepsin begins but does not complete the reduction of proteins, for proteins are very complex substances which are not completely reduced until they are acted upon by the fluids of the intestines. Pepsin converts certain proteins into peptones. Rennin converts the protein of milk into casein and the pepsin further reduces the casein. The chief function of the hydrochloric acid is to furnish an acid medium for the pepsin, for pepsin can act only in such a medium. Hydrochloric acid also destroys the connective-tissue coverings of food, such as meat, and also dissolves the cellulose coverings of vegetables. The purpose of gastric digestion is to put the food into a liquid form with a high degree of acidity which begins the reduction of proteins and destroys the connective-tissue and cellulose coverings.

THE FOOD LEAVES THE STOMACH. All food is not expelled from the stomach at the same time, nor is it expelled in a steady stream, but rather in gushes. Water and carbohydrates usually leave the stomach to pass into the small intestine within fifteen or twenty minutes after entering it; whereas, fats and proteins remain from three to four hours. The food as it leaves the stomach and passes into the small intestine is called "chyme."

SMALL INTESTINE. The small intestine is a cylindrical, convoluted tube about 20 feet long, which connects with the pyloric end of the stomach. For convenience of description, the small intestine is divided into three parts: (1) the *duodenum*, about 11 inches long, which connects with the stomach; (2) the *jejunum*, about $7\frac{1}{2}$ feet long; and (3) the *ileum*, approximately $11\frac{1}{2}$ feet long.

INTESTINAL DIGESTION. In the intestines, there are two sets of glands: (1) those called "Lieberkühns" after their discoverer, which secrete four important enzymes, (a) *erepsin*, which further reduces proteins, (b) *invertase*, which acts upon cane sugar (sucrose), (c) *maltase*, which acts upon the maltose formed by the digestion of starches, and (d) *lactase* which acts upon lactose

(milk sugar) ; and (2) the glands of Brünner which secrete *enterokinase* of which we shall speak later. The food in the small intestine is further acted upon by other enzymes than those secreted in the intestine itself. About three inches from the point where the duodenum joins the stomach there are two ducts (tubes which convey the secretions of the body), one the *pancreatic* or *duct of Wirsung*, and the other the *bile duct*. The duct of Wirsung conveys the secretion of the pancreas to the intestines, where the enzymes of the secretion assist the digestion of the food.

THE PANCREAS. The pancreas is an elongated organ lying in the loop which is formed by the stomach and the duodenum ; it weighs about three ounces, is approximately six inches long and two inches wide. Its secretion, the *pancreatic juice*, is alkaline, similar in appearance to the saliva and contains a substance called "trypsinogen" and two important enzymes. Trypsinogen, in conjunction with the enterokinase, forms *trypsin*, a powerful enzyme, which completes the reduction of proteins. It will be recalled that the pepsin of the stomach reduces proteins only to peptones, while the trypsin reduces these peptones to amino acids, a form which can be absorbed quite readily. The first enzyme, *amyllopsin*, reduces to maltose any starches which may have escaped the action of the saliva, and, since complex sugars, such as maltose, sucrose, and lactose cannot be absorbed by the body, they are reduced to simple sugars by their specific enzymes: maltase, sucrase, and lactase. The second, *steapsin*, reduces fats by changing them into glycerin and fatty acids. Before the action of steapsin, the fats have become emulsified ; i.e., the larger fat globules are broken up mechanically into smaller globules. After emulsification, the fats are easily reduced by steapsin into fatty acids and glycerin. The fatty acids then unite with the alkalis of the intestines, forming soaps, in which form they are readily absorbed.

A question may here present itself ; namely, what causes the pancreas to pour out its secretion at the proper time ; that is, just as the duodenum obtains the food ? The reason seems to be that the acid chyme, when it comes from the stomach, really stimulates a secretagogue in the mucous membrane of the duodenum which, when carried to the pancreas by the blood, stimulates the pancreas in turn.

In the pancreas, too, one finds other cells scattered in patches, not connected with a duct, but which pour their secretion directly into the blood. These patches are called, after their discoverer, "the Islands of Langerhans"; and their secretion, which regulates the storage of sugar in the skeletal muscles and liver, is called "insulin" from the Latin *insula* meaning island. If these islands become diseased, excessive amounts of sugar make their appearance in the blood and a morbid condition known as *diabetes* results. This may be corrected by injections of insulin obtained from the pancreas of animals.

THE LIVER. The liver, a reddish-brown gland, is the largest one in the body, weighing in adult man, something over four pounds. It is located directly beneath the diaphragm toward the right side of the body and extends well over beyond the midline of the body. It is divided by five grooves into lobes. It has five chief functions: namely, the destruction of senile red corpuscles, the conservation of body temperature, the maintenance of the fluidity in the body of the blood, the storage of sugar in the form of glycogen or animal starch, and lastly, the secretion of the bile.

The bile is a golden colored, highly viscid, bitter-tasting fluid, whose function is to aid in the reduction of fats. The bile contains no enzymes, the active agents in digestion, but, nevertheless, it assists, by virtue of its alkalinity, in the emulsification of fats.

Another important function of the liver, already mentioned, is the storage of sugar therein in the form of glycogen. When more sugar than is needed by the body is taken in, it does not go to waste, but is stored up for future needs. In its natural state, sugar cannot be stored in the body because it tends to osmose into the blood stream; therefore, it needs to be changed into a form incapable of osmosis, such as glycogen. When a need for additional sugar arises, the stored-up glycogen is changed back again into sugar. The liver may contain as much as 10 per cent of its weight of glycogen.

Food which has been reduced into simpler substances is absorbed; while, on the other hand, substances ingested but incapable of digestion are passed on to the large intestine.

LARGE INTESTINE. The remainder of the alimentary canal extending from the ileum to the anus is called the "*large intestine*."

It is divided into three parts: the *caecum* which connects with the ileum and to which the appendix is attached, the *colon*, and the *rectum*. It is about $4\frac{1}{2}$ feet in length. Though much shorter than the small intestine, it is called "large" from its superior diameter. The large intestine absorbs a little water from the undigested feces, otherwise, its only function seems to be that of temporarily providing a storage room for the feces until they are discharged (defecation, or egestion).

ABSORPTION. Absorption is that process by which the digested food passes from the alimentary canal into the blood stream and lymph. The chief organ of absorption is the small intestine, though extremely small amounts of peptones, sugars, and water may be absorbed directly by the stomach.

The alimentary canal, as we have already seen, is lined by a single layer of compact cells forming a mucous membrane. Between this mucous membrane and the muscular coats, there is a layer of loosely arranged cells called the "submucosa," which projects into the small intestine in fingerlike processes called "villi." In the central core, or submucosa, of each villus are blood capillaries and lymphatics, which are called "lacteals" (a lymph vessel in each villus).

The simplified proteins and carbohydrates pass through the mucous membrane into the blood capillaries or, in other words, are absorbed by the blood. This passage of simplified foods into the blood is accounted for partly by the physical processes of osmosis and diffusion, and partly by the activities of the cells of the mucous membrane. The emulsified fats are absorbed by the lacteals of the villi, whence they are conducted by minor lymphatic ducts to the large *thoracic duct* (the largest lymphatic vessel in the body) which terminates at the junction of the left jugular and left subclavian vein beneath the left collar bone. In this way the fats reach the blood stream into which the other simplified foods have already made their way. Through the general circulation, all these simplified foods are carried throughout the entire body, and the various cells with which the blood and lymph come in contact remove such foods from them as the cells need.

CIRCULATORY SYSTEM

THE BLOOD. Blood primarily consists of a watery substance called "plasma," in which minute bodies, *corpuscles* and *blood platelets* are floating about, and *nutriment* derived by absorption chiefly from the small intestines. It is not a lifeless fluid, but a *living circulating tissue*. In vertebrates it appears red in color, is viscid, and is possessed of a salty taste. There are about five quarts of blood in the human subject.

The corpuscles of the blood are of two kinds: red, and white. The function of the red corpuscles (which give the blood its characteristic red color, there being about 5,000,000 to the cubic millimeter) seems to be that of serving as the "carriers" of oxy-

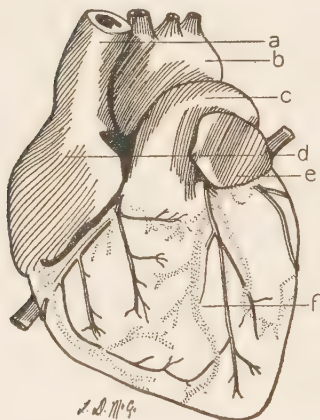


FIG. 54

Diagram of Human Heart, Anterior View. a, Superior Vena Cava; b, Aorta; c, Pulmonary Vein; d, Right Auricle; e, Left Auricle; f, Ventricle.

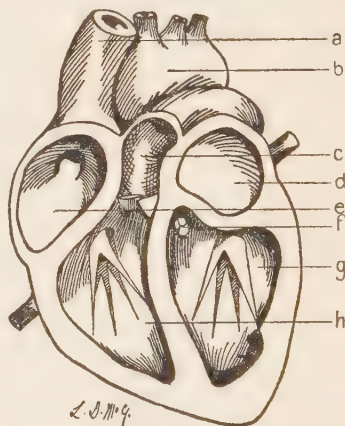


FIG. 55

Diagram of Human Heart, Opened Anteriorly. a, Superior Vena Cava; b, Aorta; c, Pulmonary Vein; d, Left Auricle; e, Right Auricle; f, Opening to Aorta; g, Left Ventricle; h, Right Ventricle.

gen to all parts of the body. This carrying of oxygen is brought about by a substance contained within the corpuscles and called "hemoglobin." This hemoglobin has a strong affinity for oxygen and as the blood passes through the lungs (pulmonary circulation), the hemoglobin unites with the oxygen. In the general cir-

culatation, the hemoglobin gives up its oxygen to the cells of the body.

The white corpuscles are the "policemen of the body"; in number they are vastly inferior to the red. In fact, there are only from 7,000 to 9,000 in each cubic millimeter under normal conditions. Blood platelets are minute, round, colorless bodies numbering about 200,000 in each cubic millimeter of blood. They function principally in the clotting of blood.

THE HEART. The blood is pumped through the body by a powerful, hollow muscle, the heart. In the human body, the heart is pyramidal in shape with rounded edges, situated below the breast-bone (sternum) with its apex slightly turned toward the left. It weighs about 300 grams, and is divided into four chambers; the upper part consisting of two *auricles*, while two *ventricles* are found at the apex (see Figs. 54 and 55).

CIRCULATION. The right auricle receives the impoverished blood returning through the veins from the general circulation, from whence it is forced into the right ventricle by muscular contraction. The walls of the ventricle, being thicker and stronger than those of the auricle, drive the blood through the pulmonary artery to the lungs with great force. Here it is purified as already described by the release of carbon dioxide and the intake of oxygen. Then it returns to the left auricle, oxygenated, to be pumped by the auricle into the left ventricle, the most powerful portion of the heart. The contracting ventricle then drives it with tremendous force (causing the "heart beat" at the rate of seventy pulsations per minute in the adult male and eighty in the adult female) through the general circulation throughout the entire body.

Blood vessels which carry blood away from the heart are called "arteries," while those returning it are called "veins." Thus it will readily be seen that the arteries of the general circulation and the veins of the pulmonary circulation both carry pure or oxygenated blood, rich red in color, while the veins of the general circulation carry impure or impoverished blood.

The large artery which leaves the heart (the aorta), divides and subdivides, until its ramifications extend through the whole body and it becomes attenuated into tiny hairlike vessels called

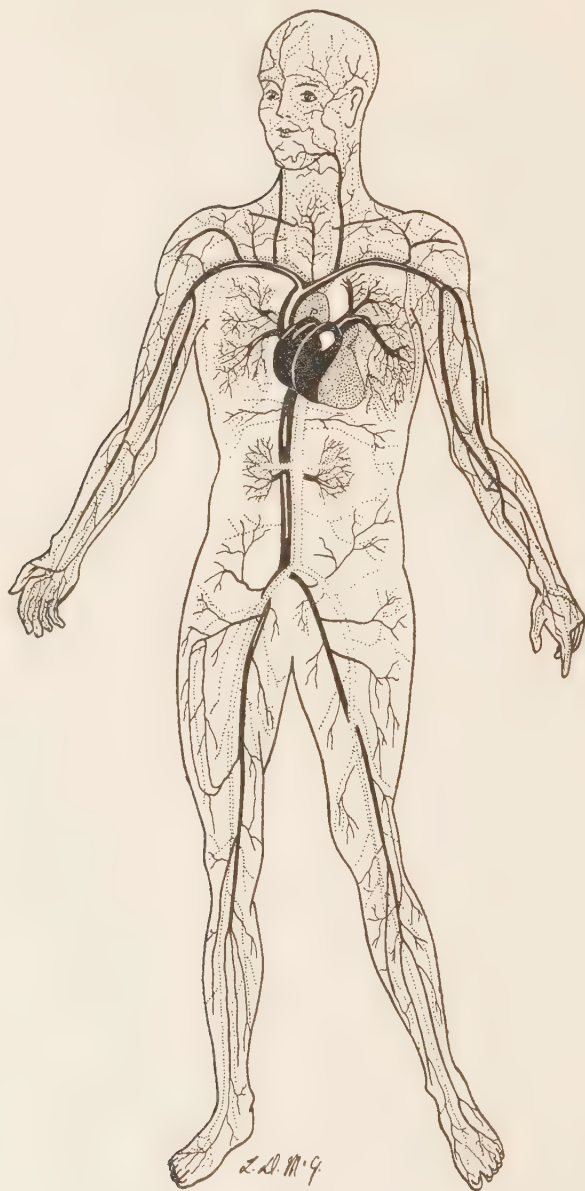


FIG. 56

Diagram of Circulatory System. Broken lines represent Arteries; Black lines represent Veins (modified after Gervais).

"arterial capillaries." From the capillaries the oxygen, by osmosis and diffusion, passes into the surrounding cells. Some of the liquid part of the blood which contains nourishment, but does not contain red corpuscles and is known as "lymph," seeps out through the walls of the capillaries so as to bathe even those cells which are not reached by the blood proper within the blood vessels. Thus every cell in the body is able to receive whatever nourishment and oxygen it may need, and, at the same time, is afforded the opportunity of discharging its waste products. The lymph is then gathered by the various lymphatic vessels through the large thoracic duct and poured back into the blood stream as already stated. Through other venous capillaries which gradually coalesce into small veins that in turn unite to form greater veins, which ultimately fuse into the *vena cava* ascendens and descendens, the whole stream of impoverished blood returns back to the heart (see Fig. 56).

ASSIMILATION

The nourishment which the cells of the body take from the blood and lymph is transformed by these cells into living protoplasm which is deposited among the already existing particles of protoplasm to produce that growth by intussusception mentioned in an earlier chapter, a process called "assimilation."

KATABOLISM

Let us now consider the second step in metabolism, namely, katabolism; i.e., the breaking-down process, by which the protoplasm which was formed by anabolism is broken down into its simplest components to release energy and heat. Under katabolism we must study *respiration* and *excretion*.

RESPIRATION. Respiration consists in the transference of oxygen from the surrounding medium to the tissues of an organism, and of carbon dioxide from the tissues to the surrounding medium. The process of respiration is composed of two phases: (1) *external respiration*, or the transference of oxygen from the surrounding medium to the blood, and of carbon dioxide from the blood to the surrounding medium, and (2) *internal respiration*, or the interchange of gases between the blood and the tissues.

ORGANS OF RESPIRATION. There is about 21 per cent of oxygen

in the air, and it is from the air that we obtain this element. In man, air passes through the nostrils (or in cases of incorrect breathing through the mouth) into the windpipe or trachea, a cylindrical tube about $4\frac{1}{2}$ inches long with walls of cartilaginous rings to insure constant distention. Just before entering the lungs, the trachea divides into a right and left bronchus. These bronchi break up inside the lungs into smaller divisions called "*bronchioles*," which in turn divide into *infundibula* and the *infundibula* into *alveoli* or *air sacs*. The *alveoli* are lined with a single layer of flat cells in direct contact with the blood capillaries. As the blood courses through the lungs, oxygen from the air diffuses into the blood which in turn gives up carbon dioxide (external respiration). The enriched blood, in conjunction with the lymph, carries the oxygen to all parts of the body and in return receives carbon dioxide (internal respiration).

The upper part of the trunk which contains the lungs and heart is called the "thoracic cavity." This cavity is capable of expansion and contraction. In expansion, the ribs, forming the sides of the body, are pulled outward by the muscles, and the diaphragm descends, thereby increasing the size of the thoracic cavity. Along with this increase in size of the thoracic cavity, there is an increase in the size of the lungs and a decrease in the pressure of the air within the lungs. To establish a normal air pressure, the outer air rushes into the lungs, thus producing inhalation or inspiration. When the muscles relax the ribs return to their former position while the diaphragm ascends to compress the lungs and to force out their contents, thus producing exhalation or expiration.

PHYSIOLOGICAL OXIDATION. *But why this need of oxygen?* From the earliest times, it has been known that animal life is dependent upon air, that shutting an animal off from access to the air meant certain death. But it was not until a comparatively recent period, the end of the eighteenth century, that the twofold mixture of gases in the air was discovered, together with the fact that it was upon one of these that life, as we understand it, depends. This substance, now called "oxygen," thereupon received the name of "vital air."

Animals exposed to air from which the oxygen has been re-

moved soon perish; whereas, if exposed to undiluted oxygen they go mad and die. It has also been shown that this "vital air" is at the bottom of all the activities included under the terms of burning or combustion, for without "vital air" there could be no combustion, while when oxygen is supplied in great quantities, combustion becomes evermore intense. It was Lavoisier, the celebrated French chemist, who showed that animal heat, just as the heat from a fire, was nothing more than the result of the union of this "vital air" with the combustible substance in the body, and that from this union, water and carbon dioxide were formed. Lavoisier even measured the amount of heat produced by this combustion in the animal body, showing that a guinea pig produced the same amount of heat and carbon dioxide as a burning candle.

In a study of the marvelous material progress achieved by man since the invention of the steam engine, it would be hard to overestimate the value of energy released by the burning or oxidation of coal. So, too, in the case of living beings, energy exhibited in their vital functions is obtained by the burning or oxidizing of the combustible substances of the body, *the oxygen uniting with the carbon and hydrogen of the food to form carbon dioxide and water.*

Carbon dioxide, being the result of oxidation, prevents further oxidation. Thus a burning substance placed in carbon dioxide will be extinguished, while living things placed in such an atmosphere will perish. Carbon dioxide then, being injurious to life, must be eliminated whenever it is formed by oxidation in the living body. The continuity of the vital processes is just as dependent upon the removal of waste products as upon the intake of food.

EXCRETION

That process by which the waste products of metabolism are removed from the body is called "excretion." It should be clearly kept in mind that substances appearing as excretions were once a part of the body, and it is in this fact, that excretion differs from egestion. Egestion is the removal from the intestines of undigested substances—substances which could not be used by the

body and were technically, never a part of the body; in fact, they never were within the body.*

THE EXCRETORY SYSTEM. The chief excretory organs are the lungs, skin, and kidneys; the chief excreta are carbon dioxide, water, and urea. Carbon dioxide, as already stated, is removed through the lungs. Some of the water which results from metabolism passes out through the pores of the skin, being secreted, along with traces of salts, by the sweat glands, a process known as "perspiration."

Urea, which is the waste product formed in the liver by the oxidation of proteins (which as we have seen are nitrogenous compounds), is highly poisonous.

THE KIDNEYS. The kidneys are usually referred to as the excretory organs, *par excellence*, for through them all the urea, as well as some 50 or 60 per cent of the water and traces of carbon dioxide, oxygen, and nitrogen, are eliminated in the form of urine, a transparent, amber-colored fluid, acid in reaction, and bitter in taste.

The kidneys, two in number, are reddish-brown, bean-shaped organs lying behind the viscera on either side of the backbone. The inner surface; i.e., the surface toward the backbone is concave. Through this concavity, blood vessels enter the kidney, and the ureters pass out of the kidneys. A ureter is a small tube about 12 inches in length; there is one for each kidney (see Fig. 57).

Internally the kidney consists of an immense number of tubes, (uriniferous tubules), enmeshed in blood capillaries. One end of each of these tubules ends in a cuplike depression (Bowman's capsule) resembling the tip of a glove finger which has been pushed inward. In each capsule there is a tuft or knot (glomerulus) of small arteries. The other end of each uriniferous tubule opens into the ureter.

*"Within the body" is here used in a strictly technical sense; that is, actually contained in the living tissues, and not merely contained in some interior cavity or passage. Thus, for instance, a grain of dust could be lodged in the windpipe or lungs; or other extraneous matter might find its way into the alimentary canal, without being technically "within the body." Thus undigested foodstuffs or indigestible ruffage have been, in the popular sense, "within the body" from the moment they were taken into the mouth, until ejected in the form of fecal matter, yet they have never been "within the body" in the technical sense. In a word, whatever is contained between the external integument or skin, and the digestive tract is technically "within the body"; and whatever lies outside of the skin or while it is within the intestinal tract, even though it be on the surface of the most deeply seated mucous membrane, is considered technically, "outside the body."

There have been many theories advanced to explain the functioning of the kidneys. One of the earliest held was that the kidneys simply filtered or strained the blood free from waste matter. Recent investigations, however, seem to show that the removal of waste water and inorganic salts is due to filtration, osmosis, and diffusion taking place in the glomeruli; whereas, the urea, the nitrogenous waste, is removed through the special activity of the cells of the uriniferous tubules.

The waste material, (of which water constitutes about 95 per cent), exudes constantly from the open ends of the uriniferous tubules into the ureters, passing a few drops at a time by peristalsis into the bladder. The bladder is a musculo-membranous sac about the size of a large orange. From the bladder the urine passes to the outside through the urethra.

METABOLISM OF CARBOHYDRATES, FATS, AND PROTEINS

Carbohydrates, by the action of ptyalin, amylase, invertase, lactase, and maltase, are changed into simple sugars, and it is in this form that they are absorbed by the blood, constituting the chief sources of energy which the living body possesses. When they are present in excess, they are stored not only in the liver, but also in the skeletal muscles in the form of glycogen, to remain thus stored until needed by the body.

The value of carbohydrates as a source of energy was universally recognized in the late war, as evidenced by the large rations of sugars in different forms, especially chocolate, which were served out to the combatants.

Fats are changed into soaps by the action of steapsin and the alkalis in the small intestine, in which form they are absorbed. Though the chief purpose of fats seems to be to produce heat in the body, they also yield energy. Fats, when oxidized, also form carbon dioxide and water, as waste matter. Excess fats are stored up in the body in the form of adipose tissue.

Proteins are reduced to amino acids by the action of pepsin, erepsin, and trypsin in which form they are absorbed. Their purpose is to rebuild protoplasm. Consequently, they are absolutely essential to all living things, and without them all organisms would soon die. Proteins, unlike fats and carbohydrates, are not

stored up in the body, and when oxidized yield urea.

The relative parts played by the three classes of foodstuffs in the human body may be expressed thus: (1) proteins are absolutely essential for the maintenance of life. Nothing else can do their work.* (2) Fat and carbohydrates, although highly conducive to the well-being of the body, are not absolutely essential to its existence, as life can be maintained in their absence. Thus, in the case of starving men, fats, and carbohydrates stored up in the body will gradually be consumed and a plump individual will become emaciated. Only, however, after the supply of proteins has been cut off does the individual die.

REPRODUCTION

Another characteristic which distinguishes living things from nonliving is their capacity for propagating themselves.

Just as there are certain organs of the body which are set aside for the purpose of digestion, so there are other organs given over to reproduction. These organs form cells, called "gametes," which are capable of developing into new beings. In man, as in the higher forms of animals, these cells are of two types: those formed in the reproductive organs of the male and known as "spermatozoa" (sperm, or male gametes); and those formed in the female called "ova" (eggs, or female gametes). When a spermatozoon and an ovum fuse together, a new single cell is formed, called the "zygote" which then begins growing into a new individual, the embryo, which develops, under favorable circumstances, into a new individual that in all essentials is a replica of its parents.

MALE REPRODUCTIVE ORGANS. The "testes" of the higher vertebrates are compact glands composed of a vast number of tiny tubes (*seminiferous tubules*), in their totality measuring many yards in length, in which the spermatozoa are formed. Each spermatozoon is an infinitesimally small single cell. Under a high-power microscope a spermatozoon looks like a very fine thread

*NOTE: It is true that if there is an excess of either carbohydrate or fat and a deficiency of some protein the body is able to synthesize amino acids from the oxidation of the products of the fat or carbohydrate and in this way can build up some of the proteins. However, since the body is unable to synthesize tryptophane, and as this is an essential constituent of body tissue, the food protein must always furnish tryptophane if it is to meet the needs of animal nutrition. It is in this sense that we say that nothing else can do the work of the proteins.

with an ellipsoidal knot at one end and a smaller knot just next to it. Thus three distinct parts are easily recognizable in the spermatozoön: the end knot or "head"; the smaller knot, or "middle piece," also called the "neck"; and the thread or "tail." The whole spermatozoön is, nevertheless, only a single cell containing the same materials found in all other cells of the body. The head contains the *chromatin*; the neck the *centrosome*; the tail, the *cytoplasm*.

Besides the testes, there are other accessory organs whose function is to conduct the spermatozoa from the testes to the exterior. Thus from each testis there is a small tube (the *vas deferens*) which ultimately connects with the urethra and conveys the spermatozoa to it.

There are also three glands: the *seminal vesicles*, the *prostate*, and *Cowper's glands* which secrete fluids into the urethra, thus conveying the spermatozoa, as a stream does logs, through the urethra to the exterior. This mixture from all the glands together with the secretion of the mucous membrane of the urethra constitute the semen, seminal fluid, or spermatic fluid.

FEMALE REPRODUCTIVE ORGANS. Corresponding to the testes of the male in the higher vertebrates, are the "ovaries" of the female. The ovary is composed of many small sacs or vesicles called "Graafian follicles." The whole ovary in appearance is something on the order of a cluster of grapes held together by some connecting material. If we think of a cluster of grapes frozen together, the connecting ice will represent the connective tissue of the ovary; the grapes themselves the Graafian follicles; the grape seed the ovum or egg proper; and the pulp of the grape the nourishment contained in the follicle cells.

The name Graafian is derived from De Graaf, who, in 1672, first described the structure of the ovary in birds and mammals. He also first described ova passing through the oviduct, though he mistook the ova for the follicles which now bear his name. It was not until 1827 that von Baer first traced the mammalian ovum from its origin in the Graafian follicle through the oviduct to the uterus.

In each follicle, a single, unicellular, spherical ovum is formed containing similar materials to those found in all other cells of

the body, plus a few yolk granules, mitochondria, and rarely a minute centrosome.

When an ovum has matured or is "ripe," it breaks forth from the follicle and passes through the oviduct on its way to the uterus or womb. There are two such oviducts or "Fallopian tubes," one for each ovary. They are so-called from the celebrated anatomist, Fallopius (1523-1563), who first described them. These Fallopian tubes are not connected directly with the ovaries, but lie in close proximity to them, the end nearest the ovaries being expanded into the shape of a funnel. The edges of the funnel are fringed; i.e., possess small fingerlike processes extending from the edges. At the time of the follicle's rupture, the funnel end of the tube, being movable, brings its fingerlike processes over the ovary to assist the ovum in entering the tube. The Fallopian tubes at their other end fuse together to form the uterus, a thick-walled, muscular, pear-shaped sac.

Since the spermatozoön and the ovum are each single cells, the question might arise as to why they differ so greatly in shape and size. An explanation for this difference in shape is to be found in the different functions each part plays in the process of fertilization. The spermatozoön has to seek the egg or ovum in the female genital tract, and to do this it must be so shaped that it can move with great ease. We are all familiar with the rapid movement of fish and tadpoles by means of the rapid vibration of their tails. The tail of the sperm is likewise capable of whipping rapidly back and forth thus enabling it to move along the moist surface of the mucous membrane in the female genital tract. In the case of the ovum, there is no movement necessary except that caused by the force of gravity. The superior size of the ovum is due to the fact that, in addition to the germ of life (nucleus of the egg), it contains certain nutrient granules for the development of the new cell or embryo in its very earliest stages before it has reached the uterus, whereas the sperm contributes only its germ of life (sperm nucleus).

FERTILIZATION. Fertilization is the union of an ovum with a sperm. In man and the higher vertebrates, only the head and middle piece of a single sperm enters the ovum, the tail, whose vibratory movements causes their entrance, remains outside and later disintegrates. Once within the ovum, the sperm nucleus

reaches the nucleus of the ovum by movements of the egg cytoplasm and both nuclei then fuse together to form a new cell; this process constitutes fertilization.

THE STORY OF THE FACTS OF FERTILIZATION. That a mutual contribution is necessary from each parent in bisexual fertilization seems to have been recognized from the very beginning of the human race, despite the fact that certain barbarian peoples or individual philosophers seem to think one or other contribution the only or the main element in generation. From the time of Aristotle however, all scientifically minded men recognized the duality of the contribution though this unanimity was broken for a time by the dispute in the seventeenth century between the *animalculists* and their rivals the *ovists*. The former, captivated by the discoveries of Hamm (1677), attributed everything or at least the greater merit in the dual process of generation to the newly discovered spermatozoön. In fact, they thought they discerned, with their crude microscopes, that the head of every sperm contained an infinitesimally small, but complete human form, which they called an "homonculus." They saw this homonculus bent together quite as the fetus is bent in the uterus. On the other hand, the ovists stoutly maintained a merely parasitic nature for the spermatozoön, attributing to it, at most, a mere stimulating effect on the ovum which they tenaciously asserted contained the future being. Thus we had only a revival in scientific guise of the previous crude notions of early savages.

Although Aristotle and his school recognized clearly the equality of the contributions of both egg and sperm, they failed in their explanation. They always spoke of a female seminal fluid, a notion strangely prevailing in many quarters almost to the present time. It was not until the time of Harvey (1578-1657) that the ovum, as distinguished from the so-called female seminal fluid, was actually recognized. From this time the axiom: "*Omne vivum ex ovo*," came into being which is now no less celebrated than the other biological axiom "*Omne vivum ex vivo*." Truisms today, they, like gigantic milestones, mark the vast steps forward in scientific knowledge.

The necessity for the actual contact of the ovum with the seminal fluid to insure fertilization was first scientifically and ex-

perimentally demonstrated by Swammerdam (1637-1680), though it was not until the time of Hartsoeker (1665-1725) that the absolutely essential part played by the spermatozoön was established. In 1780, Spallanzani actually fertilized, by artificial means, the eggs of a frog and later even induced gestation in a dog, though he failed to perceive the exact element in the seminal fluid that caused fertilization. In 1824, Prevost and Dumas, by experiment showed that filtration would destroy the fertilizing power of the seminal fluid, thus demonstrating the efficient causality of the spermatozoön. Then years later, Barry triumphantly clinched the matter by showing the actual entrance of the sperm of a rabbit into the ovum.

PLACE OF FERTILIZATION. Fertilization usually takes place in the upper portion of the Fallopian tube, although it may take place in any part of the Fallopian tube. The sperm entering the Fallopian tube may fertilize any ovum it finds there; if none is encountered it continues on its way to the upper portion of the tube where it remains for some time. It can live for a few days in such environment. If during this time an egg should break from a follicle, the sperm immediately enters and fertilization takes place.

RESULTS OF FERTILIZATION. The ovum and sperm, although highly organized cells are, nevertheless, not complete beings; they are merely necessary steps or means in the formation of a new complete being. Hence, they cannot of themselves undergo any further growth or development. An ovum that is not fertilized, ultimately disintegrates; in the same way a sperm cell dies, if it does not meet its complement, the ovum. But once a sperm and ovum unite, the new cell (called the "zygote"), thus formed from the fusion immediately enters upon a marvelous and almost miraculous career. The tiny cell, the zygote, begins to grow and by the process already explained, of cleavage or segmentation rapidly builds up into a new individual of the same type and species as the parents.

THE EMBRYO. The zygote, now bearing an embryo, travels down the Fallopian tube to the uterus and is probably assisted in its movement by the action of cilia—small, fine, hairlike processes which line the tubes. Arriving at the uterus, the embryo attaches

itself to the mucous membrane lining that organ. This membrane, in the meantime, has become thickened and is, in this state, called the "decidua." In its progress down the Fallopian tube, the embryo develops about itself two membranes: an inner one, the *amnion*; and an outer, the *chorion*. This latter develops on its outer surface many fingerlike structures—*chorionic villi*, similar to the villi of the small intestine. These chorionic villi penetrate the decidua and, in so doing, rupture many of its capillaries. The villi then rest in what has been termed "a lake of blood." In this way, through osmosis and diffusion, the nourishment from the blood of the mother reaches the embryo.

Notwithstanding popular opinion to the contrary, there is no direct interchange of blood between mother and child. Each maintains its own distinct circulation. What has been popularly thought to be a direct connecting bond between maternal and fetal circulation, namely, the umbilical cord, is in reality only a tube containing two arteries and a vein which pass from the fetus to the wall of the chorion in whose villi, dipping into the decidua, osmosis takes place. In this connection, we might mention that the chorion plus the decidua still bears the name *placenta*, a term coined before medical science had discovered the distinct nature of the chorion and decidua. It is this combination of chorion and decidua, called the "placenta," which forms the afterbirth; and it is the direct connection of the umbilical cord of the child with the chorion and the indirect connection of the cord with the decidua that has given rise to the inaccurate popular notion of an actual cord or ligament binding the unborn infant to its mother.

It is obvious that in the early days of intra-uterine life, the development of the embryo being one of the segmentation and multiplication of cells, there will be little resemblance between the newly developing individual and its later specific form. During this period of transition, it is generally known as the embryo; when its development has so far progressed that rudimentary organs and a more or less generic resemblance to its specific form is recognizable, (at about the end of the third month in man) it is called the "fetus." Embryonic and fetal life combined, comprise what is called the "period of gestation"; among human beings, this is normally nine months, though the child is viable;

that is, capable of living outside the womb, if born after the seventh month.

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CHAPTER XV

ENDOCRINE GLANDS

Elsewhere we saw that the vertebrate organism is composed of a number of organs, each with a specific function, and working in harmony with all the others to attain one definite purpose: the well-being of the whole organism.

For the sake of clarity, let us make a comparison between vertebrate organisms and manufacturing establishments. In the factories, each department, like each organ of the body, has its own special contribution to make, and all these special contributions are later assembled into some complex machine, for the manufacture of that product for which the plant is established. For the proper coördination of these various departments, there must first be a guiding or directing force linking all these various departments into a single unit. This unifying and directing force is found in the board of directors, the superintendents, and the foremen of the factory. In addition to the foregoing, an efficient manufacturing plant will have other forces; namely, various experts in its chemical laboratories, who exert tremendous influence upon the policies and decisions of the board of directors and through them in turn, upon the various departments.

In vertebrate organisms, we find two somewhat similar systems of control: The first, corresponding to the board of directors, the superintendents, and the foremen of the factory, is the *nervous control* exerted by the nervous system; the second, corresponding to the experts in the chemical laboratories of the factory, is the *chemical control* exercised by the endocrine or ductless glands.

The present chapter has to do with the chemical controls of the body, but before beginning any discussion of them, it is well to show why such controls are necessary and even indispensable to the well-being of the organism.

It is common knowledge that the environment in which we live is constantly changing, at least in its minor details. Some of

these changes are immediately apparent to everyone, while other changes are visible only to the careful investigator. Thus, in summer, the days are long, the temperature high, and the rainfall heavy. In this environment, the trees bear leaves, the flowering plants bring forth their blossoms, hibernating animals, like the frogs, come forth from their winter quarters and mate; fur-bearing animals shed their heavy coats. In fall and winter, our environment changes again. The temperature is greatly reduced, the days are shorter, the rainfall is lessened, snow and ice appear, and we find the plants and animals again adjusting themselves to these changes. The fur of the animals becomes thicker and the feathers of the fowl more numerous. The trees, on the other hand, lose their leaves and "cork up," as it were, by the formation of scales or scabs over the tiny openings of the canals which permitted communication between the leaves and other parts of the tree during the summer. Plants and animals, if they are to continue to survive, must adjust themselves to environmental changes and this, as everyone knows, they do.

Again, living things possess the power of adjusting themselves to changes in their own bodies; i.e., their internal environment. Thus, if all the branches are removed from one side of a tree, the remaining branches grow to a larger size than they would ordinarily do. Likewise, in the animal kingdom, we see similar conditions obtaining. Thus, if one kidney is removed, its mate grows twice as large. Lower animals, such as lobsters, earthworms, and even some reptiles can replace a claw, leg, or tail that has been lost. Thus we find that plants and animals make notable and almost inconceivable changes in their bodily structure so as to maintain their normal functions.

Examples to the point are also the bodily changes accompanying many of our emotional states. When we are angered or frightened, our faces grow pale, the pupils of the eyes dilate, the heartbeat is quickened and becomes more forceful, our blood pressure rises, and even the muscles become taut giving us greater strength. Anyone who has ever attempted to rescue a drowning man will testify to this adjusting of the body to varying contingencies.

ENDOCRINE GLANDS NOT MERELY RUDIMENTARY ORGANS

Much of typical glandular functioning in the animal organism has been referred to in previous chapters, but it will be remembered that all the glands mentioned possess ducts by which their secretions are carried to various parts of the body. Such glands, as possess ducts, are called "exocrine." In addition to these typical glands, there are other bodies of glandular structure, but without ducts, which earlier investigators correctly called "ductless" and put down, because they could not fathom their functions, as merely vestiges of primordial organisms "outgrown in the course of evolution." It was, to say the least, a rash assumption that, because they did not recognize the purpose or function of these glands, the glands had no function. This cocksure assignment of the ductless glands to the rôle of evolutionistic vestiges held up for some time what has been a source of most profitable inquiry.

It was not until operative surgery removed these ductless glands, when in a diseased condition, and failed to restore the health sought for, that medical thinkers began to realize that there was some subtle connection between these so-called vestiges and bodily health. In many cases, removal of these glands produced new organic difficulties of a serious nature. From this it was concluded, that though these glands do not have ducts through which they make visible or tangible contributions to the blood stream, they do, nevertheless, have a tremendous influence upon animal economy either by taking noxious elements out of the blood stream or by modifying the elements of the blood so as to bring about bodily health. This, then, was the starting point of a new, and what promises to be a marvelous expansion of medicine known as "endocrinology," or the science of the ductless glands.

Of the glands now known as ductless or endocrine, four, the pituitary or hypophysis, the thyroid, the thymus, and the pineal or epiphysis, were known to the ancients and were more particularly described by Vesalius and Eustachius in the sixteenth century. Eustachius added to this number the suprarenals. The parathyroids were discovered and described as late as 1880 and their independence of the thyroid was established in 1899. The pathological knowledge of these glands lagged far behind the anatomi-

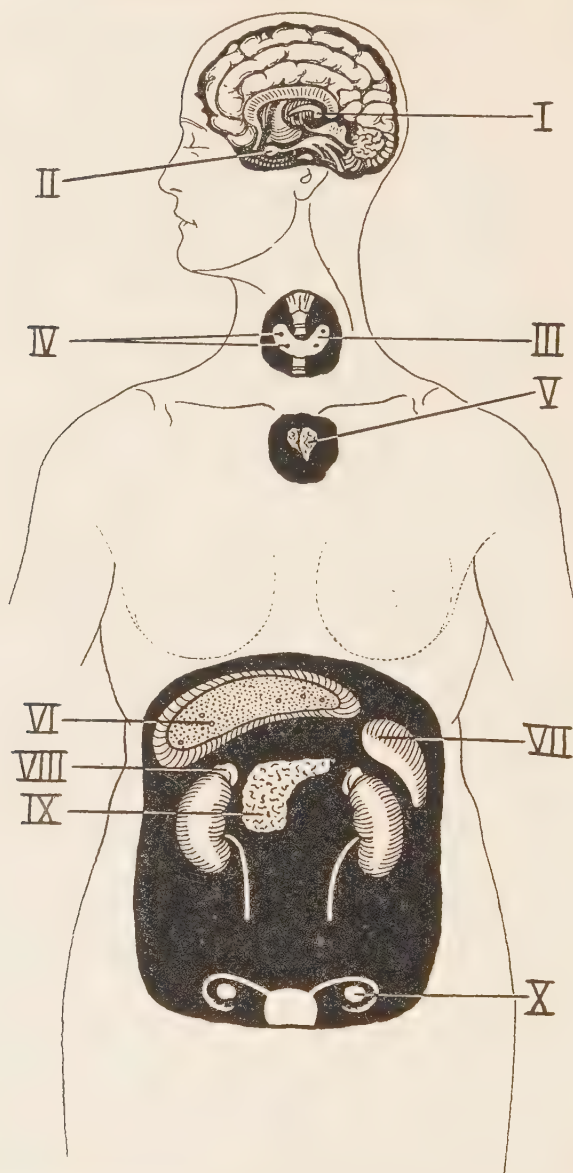
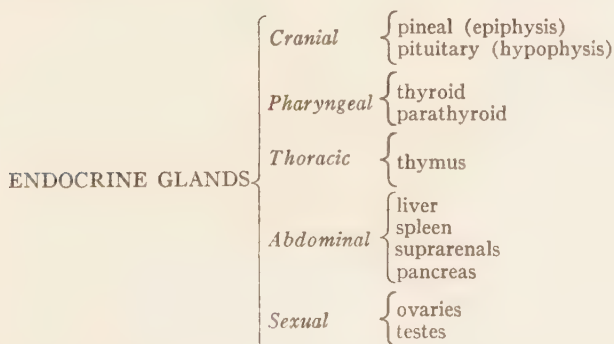


FIG. 57

Diagram showing Endocrine Glands. I, Pineal (epiphysis); II, Pituitary (hypophysis); III, Thyroid; IV, Parathyroids; V, Thymus; VI, Liver; VII, Spleen; VIII, Suprarenals; IX, Pancreas; X Ovary.

cal. Not until the end of the eighteenth century, do we find the first clear description of the diseases of the thyroid by Parry, an Englishman, and in 1802, the better-known and consequently more epoch-making observations of Flajani, an Italian, followed by Graves of Ireland, Basedow in Germany, and Charcot in France. All these, and more particularly Addison, who left his name to the disease of the suprarenals (Addison's disease), and Pierre Marie in France with a host of later writers described accurately the various ailments due to wasting away, enlargement, or other morbid conditions of the ductless glands. The endocrinal functions, properly so called, are of much later discovery. Many experimenters seemed to have suspected endocrinal activity, but it was Claude Bernard, in France, in the middle of the nineteenth century, who, in the discovery of the glycogenic function of the liver, established that it had an internal secretion over and above its external secretion, the bile. This doctrine of internal secretion was put upon a firmer basis by the experiments of Brown-Sequard in France and Schiff in Germany. The application to individual endocrine glands was not established until much later. It is, for the most part, largely the work of the twentieth century.

Endocrine glands may be grouped according to their location in the body (see Fig. 57).



The substances secreted by the endocrine or ductless glands are called "autacoid," from the Greek, *acos*, signifying remedy. As remedies are either stimulating or sedative, according to their reaction upon the organism, we have a twofold division. Autacoid

substances possessing a stimulating or exciting effect, thereby inducing certain organs of the body to increased functional activity are termed "hormones," while those autacoids which exert restraint and inhibit functional activity are properly called "chalcones." Many authors, however, use the term "hormone" to designate either kind, indiscriminately.

Though all these endocrine glands are anatomically separate and distinct, nevertheless, a very close relationship and correlation exists between the secretions of these various glands. Even a slight disturbance in one of them may affect and alter the activity of all the others. This fact alone is sufficient to show, at once, the intricacy and complexity of the body in regard to these controls, and the tremendous influence which they exert upon the organism.

CRANIAL ENDOCRINES

PITUITARY GLAND. The pituitary gland, meaning phlegm, so called by the early anatomists, who discovered it, because they thought that it produced the nasal secretions, is in size about as large as a hazel nut. It is composed of two small masses or lobes, a front or anterior lobe and a back or posterior lobe joined together by a median lobe. This gland is situated in the cavity formed between the upper surface of the mouth and the under surface of the brain to which it is attached. The anterior and posterior lobes of the gland differ somewhat in their structure, and they differ greatly in their functions; whence arises the common reference to the pituitary as two-lobed. The median lobe, being structurally like the posterior, and so far as we know, possessing the same functions, is generally not considered separately but together with it.

The Anterior Lobe. The main function of this lobe is the control it exercises upon the growth of the body, particularly growth in height. This fact has been repeatedly shown by experiments upon young dogs. The removal of the greater part of the anterior lobe results in a retardation of growth and the failure of sexual development. Similar observations have been made in children, whose anterior lobes have been accidentally injured. In cases where this lobe failed to develop properly and normally, growth is retarded; the sexual organs fail to develop, and a condition

known as "dwarfism" results. On the other hand, if the anterior lobe becomes greatly enlarged in early life, the individual becomes extremely tall, chiefly through excessive lengthening of the leg bones; such a condition is called "gigantism." To this type, belong the general run of giants seen in circuses and museums.

Enlargement of the anterior lobe in later life induces the disease known as "acromegaly." The chief symptoms of this disease are excessive enlargement of the bones of the jaw, the hands, and the feet; thickening of the skin; baldness; together with abnormal mental and physical sluggishness.

In pregnancy and labor, the anterior lobe also seems to play an important part. Near the end of pregnancy, the cells of this lobe increase greatly in size and are referred to as the "cells of pregnancy."

From the anterior lobe an extract, *tethelin*, has been obtained. When this extract is injected into a subject, the smooth muscles are strongly stimulated. When fed to hens, it stimulates their ovaries thus causing an increase in egg laying.

Complete removal of the anterior lobe causes death, the symptoms being chronic diarrhea, gradual wasting away of the body, and unsteady gait due to a lack of muscular coördination.

The Posterior Lobe. This lobe exerts a pronounced influence upon the metabolism of the body. When it fails to function properly, whether due to disease or to total or partial removal by surgical operation, the subject stores up large amounts of fat and abnormal quantities of sugar, with a consequent loss of physical vigor. On the other hand, overactivity of the posterior lobe causes a rapid oxidation of fats and sugars, thus preventing a storing up of these substances in the body. As a consequence, there is an increase in the amount of urine excreted.

An extract called "*pituitrin*" is obtained from the posterior lobe. When injected into a subject it causes a slowing down of the heart, an increase in blood pressure, an intensification in intestinal peristalsis, and contraction of the smooth muscles in general. Its influence, in this last respect, upon the uterus, is so great that it was formerly used in obstetrics to correct extreme dilation of that organ.

Removal of the posterior lobe does not cause death, as is the case with the anterior lobe, but its removal powerfully affects the normal functioning of the organism.

PINEAL GLAND. The pineal gland, a tiny body, is located almost in the center of the brain mass. From its position, it was regarded by Descartes and his followers as "the seat of the soul." Because of its fancied resemblance in shape to a pine cone it was called the "pineal gland."

The pineal, in some way, is intimately connected with childhood. It reaches its maximum size in the human being about the seventh year, and thereafter gradually disintegrates until, in the adult, all that remains is a small amount of fibrous tissue.

In children, degeneration, enlargement, or removal of the pineal results in excessive development and premature functioning of the reproductive organs. It is also accompanied by an extraordinary increase in the growth of the skeleton and precocious mental development. Apparently then, the pineal gland secretes a chalone which affects sexual and mental growth, as well as controls skeletal growth.

Injections of the pineal extract simply cause an increase in blood pressure.

PHARYNGEAL ENDOCRINES

THYROID GLAND. The thyroid is located in front of the wind-pipe or trachea, just below the Adam's apple or larynx. It consists of two lobes connected by a narrow strip of tissue called the "isthmus." Examined under the microscope, the thyroid appears somewhat like a sponge with spherical chambers or holes filled with a gluelike substance, its secretion.

The thyroid is very vascular; that is, it contains numerous blood vessels and, as a consequence, receives extremely large quantities of blood. This fact alone, that the thyroid receives large quantities of blood, would lead to the surmise that the thyroid must be a very active organ with very important functions. Such a conjecture, as we shall see, is indeed most true.

In children, a diseased or deficient thyroid causes a condition known as "cretinism" in which the physical and mental development of the child is greatly retarded. The cretin is characterized by inferior stature, staring eyes, silly smile, protuberant belly,

and in general, by a backwardness in mental and physical development. Thus, a cretin, 20 years of age, would resemble in size and mentality a child no more than 4 or 5.

In the adult, a diseased thyroid results in "myxoedema" a disease characterized by thickening of the skin, puffiness of the eyelids, loss of hair, a decided decrease in physical vigor, together with a marked tendency toward obesity. In brief, a young adult becomes mentally and physically an old and feeble person.

On the other hand, thyroid enlargement results in a "simple goiter," (a large protuberance visible in the throat), a disorder more prevalent among women than men and one readily corrected by surgical operation.

Overexcitation of the thyroid results in an increase in the amount of secretion. This gives rise to a far more serious condition known as "exophthalmic goiter," often ending in insanity. The bodily symptoms show themselves in an unsightly bulging out of the eyes, intensification of the heartbeat, an increase in the amount of urine and carbon dioxide excreted, loss of muscular power and physical vigor, extreme nervousness, and a general wasting away of the body tissues. In short, every activity of the body is immediately increased, and as a result, the body "burns itself out." Overexcitation of the thyroid is thus seen to have the same result on the body that open drafts have upon fire. In other words, the burning of oxidizable substances in the body is greatly augmented and the resulting emaciation is soon followed by death.

Cretinism and myxoedema are not caused by the presence in the organism of any toxic substance, but rather by the lack of proper secretion formed by the thyroid. This has been abundantly shown by the fact that injections of "*thyroxin*," a thyroid extract containing a quantity of iodine, cures myxoedema and produces extraordinary improvement in cretinism. That iodine is the active beneficent principle in the thyroid secretion and extract is demonstrable from the fact that cretinism and myxoedema are generally prevalent in regions where there is little iodine in the soil and water, as in mountainous and inland regions (the Alps and Himalayas). These diseases are unknown on the seacoast where the abundant stores of iodine in the seawater and soil finds its way imperceptibly into the dietary of the inhabitants. Even

minute quantities of iodine given apart from thyroxin have proved useful as cures or preventives in regions long infested with cretinism. Certain Alpine valleys, which were the habitat, *par excellence*, of cretins from time immemorial, are now free from this disease. This change was effected by the artificial introduction of iodine into the diet and medicine. In this connection, it is interesting to know that, as early as the twelfth century, Roger of Palermo of the famous medieval medical school of Salerno, used iodine in the form of sponges and seaweeds in the treatment of goiter.

Although removal of the thyroid does not cause death, it does seriously affect the general metabolism of the body. This has been proved by experiments with various litters of such animals as dogs, rats, and monkeys. Shortly after the birth of the litter the animals were divided into two groups. One group was deprived of its thyroids while the other group was not. At the end of six months, the animals deprived of their thyroids weighed less than half as much as those which were not so deprived. Indeed, in the case of tadpoles, removal of the thyroid utterly prevents the change into the adult frog state, leaving us the curious phenomenon of perpetual tadpoles.

PARATHYROIDS. We have seen that complete excision of the thyroid is not fatal; nevertheless, earlier operations for its removal always resulted fatally. This fact led to the discovery of four minute endocrines buried in the thyroid, two upon either lobe, which, from their position, are called "parathyroids." Removal of these is inevitably fatal. Hence in surgical operations today for thyroid removal, the greatest care is taken not to disturb the parathyroids because it is now known that parathyroidectomy inevitably results in an alarming overexcitation of the nervous system, violent contractions of the muscles, an abnormal elimination of calcium salts from the body, and the evolution of several toxic substances otherwise not present; the subject shortly dies in violent convulsions.

The secretion of healthy parathyroids seems to neutralize the action of certain toxic or poisonous substances normally formed by the body and assists in the elimination of these poisonous elements. The overexcitation of the nervous system and the violent

convulsions which occur after parathyroidectomy seem to be caused by the accumulation in the body of substances which would otherwise be neutralized and excreted.

THORACIC ENDOCRINE

THYMUS. The thymus gland is found at the base of the heart beneath the breastbone or sternum. It is, relatively, one of the largest glands in fetal life attaining maximum size shortly after birth, and retaining it until puberty* when it begins to decrease gradually until only the slightest trace of it remains in the adult. In calves, it is very large and is sold as a popular delicacy under the name "sweetbreads of the neck."

The sole action of the thymus, so it seems, is to exercise a controlling influence upon the development of the sex glands. In young animals, where the thymus has been removed, the testes develop to an abnormal size. On the other hand, when thymus is fed abundantly to young animals their sexual development is retarded, sometimes to the extent of the actual degeneration of the testes. Apparently there is some counteraction of the genital glands upon the thymus, since in the case of castrates, the thymus is extremely slow in disappearing.

ABDOMINAL ENDOCRINES

SUPRARENALS. In all animals possessing kidneys, there are found connected or in close proximity to these organs, small masses of glandular matter called from their position "adrenals." In man, owing to their special position capping the upper end of each kidney, they are styled "suprarenals." They are composed of two parts, an outer yellowish-white fatty layer, the *cortex*, and an inner, darker-colored core, the *medulla*.

Disease of these glands is known as Addison's disease. It was discovered by Thomas Addison, who, in 1853, first pointed out its characteristic symptoms: great muscular weakness, and loss of physical vigor, accompanied by brown patches on the skin, and vomiting followed by death. Three years later, Brown-Sequard in France, showed that complete removal of the suprarenals caused a strange lethargy resulting in death in less than 48 hours.

*Note: By puberty is meant the period in life at which a person of either sex becomes functionally capable of generation. In the human male that period is reached about the fourteenth year, while in the female it is about the twelfth year.

From the medulla, an extract, *adrenalin*, in pure crystalline form, is obtained. This extract is also made in the chemical laboratory and sold under the name adrenalin chloride.

Adrenalin, in liquid form, is being constantly secreted by the medulla and is poured into the blood stream in minute quantities. The normal amount of adrenalin found in the blood is one part adrenalin in every 500,000,000 parts of blood.

Injections of adrenalin cause marked changes in the subject, the heartbeat is steadied and becomes much more forceful, fatigue is temporarily banished; there is an increase in the number of white corpuscles, the pupils of the eyes dilate, and the general strength is increased, due to an augment in the amount of sugar in the blood. Adrenalin is antagonistic to insulin, the internal secretion of the pancreas, which controls the amount of sugar permitted to pass into the blood stream. This antagonism of adrenalin toward insulin accounts for the increase in the amount of sugar in the blood, and also for the greater strength of the muscles, for by this increase in sugar, the muscles receive more fuel.

The various changes which an individual experiences when subjected to strong emotions such as fear, anger, pain, etc., are caused, in a great degree, by adrenalin. Such changes are: Paleness of the face, caused by the constriction of the blood vessels in the face; increase in blood pressure, caused by a similar constriction; dilation of the pupils of the eye, caused by contraction of certain muscles of the eye; and an increase in strength, frequently called "the strength of desperation," caused by an increase of sugar in the blood stream.

The cortex of the suprarenals seems to exert an influence on the organs of sex; because various phases of sexual life seem to be accompanied by marked changes in the cortex. During pregnancy, for example, the cortex becomes enlarged, as does the pituitary gland, and these disturbances in the cortex result in a rapid overdevelopment of the sex organs.

It is the claim of some investigators that death, following the removal of the suprarenals, is really due to the loss of the cortex only and is in no way produced by the loss of the medulla. This notion is based upon the fact that in fishes, where the cortex is always found separate from the medulla, the removal of the cor-

tex is always followed by extreme muscular weakness and death.

From the cortex an extract, *cholin*, has been obtained, whose only noticeable effect, when injected into a subject, is to slow up the heart rate and decrease the forcefulness of the heartbeat.

THE SPLEEN. Although the spleen is the largest ductless gland in the body, there is no reliable evidence, thus far, that it has an internal secretion. It is located on the left side of the body directly below the diaphragm. Examined under the microscope, it is seen to be a fibrous organ with a spongy center containing many white corpuscles and red corpuscle fragments. Hence, it is held that the spleen has the power to destroy senile red corpuscles and that it is an important center for formation of white corpuscles (lymphocytes and leukocytes). Others maintain that the spleen secretes a hormone which changes the trypsinogen of the pancreas into its active form, trypsin, though adequate evidence for this statement is lacking. At any rate, the spleen is a most distensible organ, becoming engorged with blood after every meal. Because of this fact, the spleen is considered a reservoir for the portal blood and as such, it aids in the equal distribution of blood to the organs of digestion.

Inasmuch as the spleen can be removed without dire after-effects, it seems logical to conclude that either its functions are of minor importance, or that they are readily assumed by other organs of the body, when it is removed.

THE PANCREAS. There are certain exocrine glands which possess endocrine qualities; that is, besides the definite, external secretion which they pour through their ducts, they also form and pour directly into the blood stream, an endocrine secretion. Such glands are the pancreas, liver, and the sex glands.

The pancreas secretes three important digestive enzymes which are conveyed from it to the duodenum and account for the pancreas being an exocrine gland. Nevertheless, there are also certain special cells (islands of Langerhans) in the pancreas which manufacture a secretion, *insulin*, which is poured directly into the blood stream, thus controlling the amount of sugar in the blood stream. When the pancreas fails to secrete this hormone, diabetes results.

THE LIVER. Like the pancreas the liver has an internal secre-

tion in addition to its external secretion, the bile. The liver stores sugar in the form of *glycogen* or animal starch which it changes back into sugar, and pours into the blood stream when the body is in need of fuel.

SEX GLANDS

The testes and ovaries produce, besides spermatozoa and ova (exocrine), internal secretions which have a marked influence upon organisms. Brown-Sequard was the first to produce reliable evidence to this effect. He did this by injecting himself with a testicular extract derived from a guinea pig, after which injection, he experienced improved strength, and other evidences of regenerated power and function. After determining by repeated experiments with a hand dynamometer his normal strength, which ran from 70 to 81 pounds, he injected himself with a water extract of guinea-pig testicles. As a result his grip rose to an average of 90, and a maximum of 97 pounds.

It seems to have been realized from the very day when man first began to domesticate animals for human use, that the sexual glands exerted a tremendous influence upon the physique and behavior of animals. At any rate, the castration, or mutilation of the sexual glands, if not as old as the domestication of animals, seems to be a fact as old as any knowledge we have of their domestication. The earliest knowledge we have of domesticated animals reveals the practice of castration, though naturally castration would follow domestication. Indeed, so ancient is the knowledge that castration alters very effectively the disposition, as well as the external appearance of either male or female, that it is strange scientists did not happen upon endocrinology ages ago. Besides the loss of procreative power consequent upon the excision of the genital glands, it has always been known that the so-called secondary sex characters failed to develop when castration was resorted to before puberty; while lesser, though well-marked changes, followed post-pubertal mutilation.

By secondary sex characteristics are understood all those peculiarities in the male or female body other than the actual internal and external organs of generation, and generally speaking, these are the most striking means to the ordinary individual of identifying the sex.

Perhaps the first secondary sex characteristic that will occur to one's mind is the superior size and strength of the male, a fact so well known that the few striking exceptions serve to clinch the rule. With the sole exception of some varieties of falcons, superior size in the female is found, when it does occur, exclusively in certain lower orders of being, such as spiders, horseshoe crabs, bees, ants, etc. Along with the superior size and strength in the male, there is generally associated greater energy, often amounting to ferocity and savagery as contrasted with the relative gentleness and docility of the female. The deeper voice in the male becomes more conspicuous in the roar of the lion; the bellowing of the bull; and the sweet song of the nightingale, the canary, and other singing birds. With the single exception of sweetness of voice in the human female, sweetness as well as volume always belongs to the male. The beard of man; the mane of the lion; the brilliant plumage of male birds, such as the peacock, the golden pheasant, and to a less degree, the common barnyard fowl, together with the comb and wattles, are well-known male characteristics. Even among fish, the gorgeous brilliancy of scales as found in the salmon, are characteristics of the male. Together with the superior strength and savagery of the male, may be classed the horns, tusks, and spurs for defense and offense, which though found in both sexes of some species of animals, are not developed in size and strength to the same degree in the female as in the male. In other animals, these characteristics are distinctive equipments of the male.

TESTES. If an animal be subjected to castration before puberty, there is not only a loss of all power of generation, but the secondary sex characteristics fail to develop, and in many instances, even the characteristics of the opposite sex become apparent. Thus, in the cock or male of the barnyard fowl, there is no development of comb, wattles, spurs, or the large and gaudy tail plumage, after castration. Also, the whole spirit of the bird suffers and, in place of the aggressive male, there is the inactive, gentle, and flesh-building capon of the table. An even more familiar example is the change brought about in the male of the ox family. The castrated calf, instead of developing into the thick-necked, powerful, and pugnacious bull, becomes the patient and laborious

ox, whose very horns, developing like those of a cow, reveal profound alteration which permeates the whole animal. The difference between the tender and nutritious meat of the steer, and the tough, stringy flesh of the bull is another index of the tremendous change wrought by castration. The marked differences between the mettlesome stallion and the docile gelding, between the ram and the wether, the boar and the barrow, are other instances with which farmers at least, if not all men, are familiar.

In man, where by accident or congenital defect, the testes are absent or injured, or among barbaric peoples where castration is in vogue, the same dependence of the secondary sex characteristics, such as the beard, general hairiness of the body, and the deepening of the voice, upon the development of the testes is amply shown. The smooth, hairless skin, the fat rounded muscles show the caponized condition of the eunuch.

Even after full years of development of both the primary and secondary sex characteristics, the destruction of the testes by disease, accident, or castration is marked by a loss of animal spirit and muscular vigor, by an accumulation of fat, and sometimes by the diminution of the male characteristics with certain approximations toward female features. Thus old bulls, boars, and rams, no longer wanted for breeding purposes, are castrated to fit them, as far as possible, for the table.

On the other hand, artificial renewal of the testes (grafting of portions of testes of one organism into another) seems to galvanize the whole organism into renewed activity and a renewal of pubertal sexual freshness. Voronoff grafted a testis of a 2-year-old ram into an old, feeble, decrepit, and scrawny 12-year-old ram, so weak that he could hardly hold his head up, or walk without assistance. In three months, this ram became active and stocky, grew a fine coat of wool, and five months later it became the father of a lamb. The engrafted testis was then removed and within three months, the ram once more was old and feeble. A second engrafting of a testis from a young and vigorous ram, and the decrepit old ram again was active and potent.

Another interesting experiment is that of Steinach, who engrafted testes into a spayed female and thereupon, the female acquired the sex instincts of the male.

THE OVARIES. Removal of the sex glands and the consequent effects are more generally observable in the case of the male sex. Nevertheless, similar phenomena are witnessed whenever females are born with defective ovaries or are artificially spayed. Thus, the removal or nondevelopment of the ovaries, before puberty, prevents the growth of the mammary glands and the uterus; while removal or defect after puberty causes the degeneration of these organs. In the former case, menstruation, or its equivalent in the lower animals, does not occur; in the latter case, it ceases. Injections of ovarian extracts produce or restore menstruation, as the case may be. It has even been shown by Steinach's experiments that an ovary engrafted into a castrated male rat caused this rat to assume female tendencies. Besides influencing the growth and normal functioning of the uterus, the secretion of the ovaries also seems to bring about those changes in it which are necessary for the fruitful implantation of the embryo. Experiments show that the removal of the ovaries, a few days after conception, prevents the embryo from establishing itself in the uterus and of developing.

From the foregoing, we see that the influence of the sex glands upon organisms is most pronounced. Hence, many scientists reckon the sex glands as the central glands of the whole organism.

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CHAPTER XVI

THE VERTEBRATE NERVOUS SYSTEM

The prime factor in the survival of organisms is their ability to adjust themselves to changes in their internal and external environment. Therefore, organisms must possess some means of detecting environmental changes as well as a means of transmitting the impulses set up by the environment to such cells as can make the necessary adjustments.

All organisms, as we have seen, are possessed of a fundamental property, *irritability*, and its concomitant, *conductivity*. Vertebrates possess these properties in a higher degree than do the lower forms of animal life. And just as in other respects, vertebrates are equipped with special cells for special functions, which functions in the lower animals are performed by the whole body, so too, in the case of irritability and conductivity, we find highly specialized cells exercising these functions. These highly specialized cells, when acted upon by the forces of environment, are capable of perceiving stimuli, of conducting impulses to other cells, and finally, of arousing still other cells to activity. Cells capable of such functions are termed "nerve cells," and collectively, the "nervous system."

From time immemorial the nervous tissue has been considered the master tissue of the animal organism; in other words, the monarch of the cellular community. The organism is kept in contact with all its parts through the connecting cells and fibers of the nervous system. In this respect the nervous system is like the telegraph which keeps all parts of the world in communication. Furthermore, the nervous system, in conjunction with the endocrine glands, directs, coördinates, and controls all the activities of all the cells composing an organism.

THE NEURON

The structural and functional unit of the nervous system is the neuron, the most highly specialized cell of the entire organism,

differing in size, shape, and structure from all other cells. (See Fig. 58.)

A neuron consists of a *cell body* and all its processes. The processes are of two types: the *axis cylinder process* or *axon* and the *dendritic processes* or *dendrites*.

The cell body consists of a mass of slightly granular protoplasm in which there are numerous delicate fibrils (*neurofibrils*) which are continuous throughout the cell body and its processes. In its cytoplasm are located a conspicuous nucleus and a well-marked nucleolus.

Each cell body possesses several dendrites, but, as a rule, only one axon. The dendrites are short, remaining in the immediate vicinity of the cell body. They, however, branch out in several directions, dividing and subdividing much like the branches of a tree. The axon, on the other hand, is much larger and longer, running some distance from the cell body and pursuing a rather straight course. A few branches may pass out from the axon at right angles. Such branches are called "collaterals" (see Fig. 58), of which we shall speak again in a later paragraph.

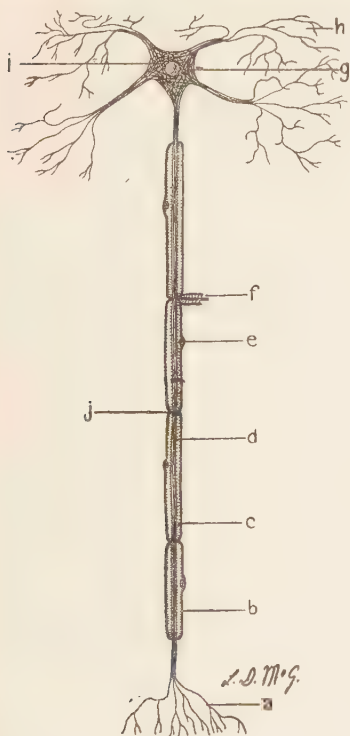


FIG. 58

Diagram of Neuron. a, Terminals of Axon; b, Neurilemma; c, Myelin or Medullary Sheath; d, Axis Cylinder or Axon; e, Nucleus of Neurilemma; f, Collateral; g, Cell Body; h, Dendrites; i, Nucleus of Cell Body; j, Node of Ranvier.

Most axons, shortly after leaving the cell body, possess two sheaths; a thin, nucleated outer sheath, the "neurilemma," and a thick, glistening, fatty, inner sheath called "myelin" or the "medullary sheath." In life, myelin is semifluid and of an oily consistency. Axons possessing both sheaths are called "medul-

lated nerve fibers"; those having the neurilemma only, are termed "nonmedullated nerve fibers."

At intervals of space, say from 80 microns to a millimeter in length, one may note a number of points where the myelin is interrupted and lacking, here the neurilemma dips down and touches the axon. Such points in a medullated nerve fiber are called the "nodes of Ranvier," and it is at these nodes that the collaterals, mentioned in the foregoing, pass out of the axon. The space between any two nodes is called an "internode" and, in the neurilemma of each internode is found a nucleus surrounded by a variable amount of cytoplasm (see Fig. 58).

The function of the myelin and neurilemma is to support and protect the axon. The myelin, moreover, is supposed to serve the same purpose that a rubber covering does upon an electric wire, namely, that of insulation, to prevent communication between adjacent neurons.

THE FUNCTION OF THE NEURON. The function of the neuron is to generate, when stimulated, an impulse and to transmit and discharge that impulse. The neuron may be looked upon as an elongated conductor with terminals at one end "picking up" or receiving impulses for transmission, and terminals at the other end discharging these impulses. The dendrites serve as points of entrance for nerve impulses coming from different neighboring cells, while the axon acts as the distributing or discharging channel.

Neurons which conduct impulses to the brain and spinal cord are called "afferent" or "sensory neurons"; those conducting impulses from the spinal cord and brain are called "efferent" or "motor neurons," while those neurons which transmit impulses between afferent and efferent neurons and from one side of the spinal cord to the other are called "adjustor neurons." As indicated in Figure 59, the cell bodies of afferent neurons are located at some distance from their terminals while the cell bodies of efferent neurons are located at one end.

Neurons, in order to function, must be connected in chainlike series, so that the nerve impulse can be passed from one to another. This chainlike arrangement is effected by the terminals of one neuron coming to lie in close contact, but without direct con-

tact, with the dendrites of a neighboring neuron. Such a point of contact affords functional unity in the nervous system and is called a "synapse" (see Fig. 59).

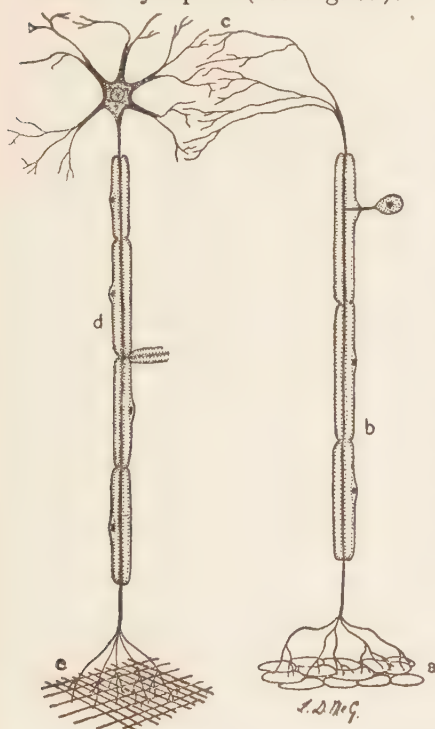


FIG. 59

Diagram illustrating a Synapse. a, Receptor; b, Sensory Neuron; c, Synapse; d, Neuron; e, Effector.

An apt illustration of a synapse can be had by placing the fingers of the right hand around the index finger of the left hand. The index finger of the left hand will then represent the terminal of one neuron and the fingers of the right, the receiving dendrites of a neighboring neuron. If the hands are now pulled apart, some idea will be given of what takes place in a subject when anesthetics are applied, such as ether or chloroform. In an anesthetized individual, the parts of the neurons forming synapses are so separated that impulses cannot be transferred. One reason advanced for this separation is that the fatty substance of the nerve tissue is dissolved by anesthetic, thus causing retraction of the nerve tissue.

WHAT IS A NERVE?

What is ordinarily called a nerve, such as the sciatic or optic nerve, is really a collection of thousands of nerve fibers into bundles. The sciatic nerve alone has some 300,000 of these nerve fibers.

Nerve fibers are gathered and held together in smaller bundles by connective tissue called the "endoneurium" while groups of bundles, in turn, are held together in larger bundles by additional

connective tissue substance called "perineurium." And lastly, several such larger groups of bundles are held together by an outer fibrous sheath called the epineurium. It is this epineurium with all its contained bundles of nerve fibers (numbering many thousands of individual fibers) that constitutes what is popularly called a "nerve." Thus a nerve may be compared to an electric cable which consists of a great number of bundles of electric wires, each wire and bundle being separated from all others by some insulating substance, the whole being inclosed in a protective waterproof coat.

THE NATURE OF THE NERVE IMPULSE. The ancients considered the nerves as tiny tubes filled with an airy substance which they called "animal spirits." It was supposed that impulses were conveyed through this substance as sound is carried through the air. Later, however, it was thought that the nerves contained a fluid called "animal juices," and that the impulses were carried along on a system of waves such as is generated when a rubber tube filled with fluid is sharply tapped. These conjectures proved to be erroneous. Nerves are neither hollow tubes nor is their protoplasm fluid.

Others have thought that impulses were actual electrical discharges conveyed along the nerve as a current of electricity is carried along a wire. This notion depended largely upon what are now obsolete ideas of how electricity worked. There is in fact a slight analogy, but the identity of the nerve impulse with the electric current is precluded by the fact that if a moist thread be tied about a nerve the impulse cannot pass, whereas, an electric current is not impeded in that way. Again, an electric current travels at least two million times faster than does the nerve impulse. It is true that an electric current does occur concomitantly with the transmission of nerve impulse, but this concomitance by no means proves the identity of nerve impulse and electric current.

At present it is thought that the nerve impulse is transmitted by a chemical reaction traveling along the nerve fiber, just as the combustion process is conveyed along a line of gunpowder which has been ignited at one end. The exact nature of the nerve impulse is not only thus unknown but even its method of transmission is thus far also unknown.

THE VELOCITY OF THE NERVE IMPULSE. Careful and repeated measurements have shown that an impulse travels along the nerve of a frog at a rate of about 85 feet per second. In man the rate is three or four times more rapid, the estimated speed being that of some 350 to 400 feet per second. The rate with which an impulse travels is dependent upon many and various conditions of the nerve over which it passes. Thus, for example, heat will increase the rate of transmission; cold will reduce it, and freezing will abolish conductivity altogether.

RECEPTORS AND EFFECTORS. Nerve fibers are not as well adapted for the reception of impulses as for their transmission. Consequently, there are certain highly specialized organs in the animal body for the reception of stimuli. Such highly specialized structures which receive impressions of a *single specific nature* are termed "receptors" or "sense organs." Five of these special sense organs are normally named: the eyes, the ears, the nose, the tongue, and the skin; that is, those receiving the sensations of sight, sound, smell, taste, and touch. Such sensations are called "special sensations." However, modern psychologists and physiologists have added many others such as hunger, thirst, pain, muscle sense, equilibrium (located in the semicircular canals of the inner ear), fatigue, and the sense of well-being. These are called the "common senses" and the sensations resulting from their stimulation are styled "common sensations."

The distinction made between the special sensations and the common sensations is that the former pertain to objects existing outside of the organism; the latter pertain directly to the organism itself. Thus when we hear a sound we do not think of our ears or brains but of some object outside ourselves which may have produced the stimulation. On the other hand, when we are hungry, thirsty, or tired we refer those sensations directly to our own bodies.

The sense organs or receptors are, of course, not the only ones which respond to stimulation. There are other organs which respond to the stimulation affecting the receptors. Such organs which produce or effect a change in an organism in response to a stimulus received by a receptor are termed "effectors." The glands and the muscles are effectors. An example may help to



FIG. 60

Diagram of the Nervous System. a, Brain; b, Spinal Cord; c, Spinal Nerve; d, Autonomic Nerve with Ganglion; e, Pulmonary Plexus; f, Solar Plexus; g, Hypogastric Plexus (modified after Gervais).

clarify this point. If while looking into a mirror, we flash a light into our eyes we will see the pupils of the eyes contracting. What has happened is that the receptors in the eye were stimulated by the light rays and an impulse was sent along an afferent nerve to the brain, from the brain a message was sent along an efferent nerve which actuated certain muscles (effectors) of the eye thus causing the pupils to contract.

The *receptors* may then be called the "windows" of the animal body, for through them the organism becomes aware of its environment. The *effectors*, on the other hand, may be called the "adjustors" of the organism because by means of them the animal adjusts itself to its environment.

DIVISIONS OF THE NERVOUS SYSTEM

It is customary to divide the nervous system of the vertebrate organism into three parts: (1) the *central nervous system* consisting of the brain and spinal cord; (2) the *peripheral nervous system* consisting of the cranial nerves (nerves from the brain) and spinal nerves (nerves from spinal cord); and (3) the *autonomic* or *sympathetic* nervous system composed of a separate set of nerves which are joined with the central nervous system. This division of the nervous system into three parts might lead the reader to believe that each part is absolutely separate and distinct from the other parts. Such an inference, however, would be erroneous, for the three are intimately united into one great system (see Fig. 60).

For the sake of clarity, let us compare the nervous system with the telephone system of a great city. The central nervous system represents the central telephone office; the peripheral system represents, for instance, the commercial exchange, and the autonomic system represents the residential exchange. Now, in the case of the telephone system, one would not consider the two as separate from the central telephone office for all three parts are, of course, intimately associated with all other parts of the entire system. Likewise in the nervous system each part is not separate and distinct but is intimately united to form one great system.

THE CENTRAL NERVOUS SYSTEM. In the early life (embryonic period) of a vertebrate organism, the ectoderm (a germ layer)

forms a groove (neural groove), the edges of which begin to roll up to form a thin-walled closed tube. The walls of the tube then thicken and the cavity within becomes correspondingly smaller. The anterior (head end) end of this tube is destined to become the brain. Consequently, we find the newly formed tube gradu-

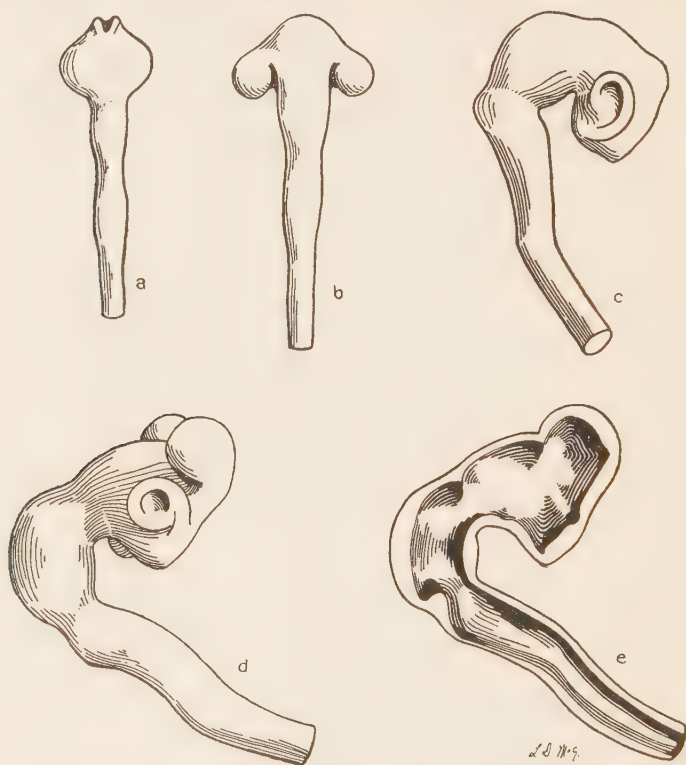


FIG. 61

Diagram illustrating successive steps in development of the Brain of the Chicken. e, Sagittal section through Brain.

ally dividing into a series of chambers due to the folding and unequal growth of its walls. Exteriorly, the outgrowth of these walls appear as swellings, while cavities, which are continuous with one another are found within (see Fig. 61).

Five parts of the brain are discernible: the forebrain, the 'tweenbrain, the midbrain, the hindbrain, and the afterbrain. In

the lower vertebrates such as frogs, reptiles, etc., (see Fig. 62) each of the five parts are immediately apparent, while in the higher vertebrates certain parts of the brain grow more rapidly than do other parts and therefore, overhang them. Thus in man the

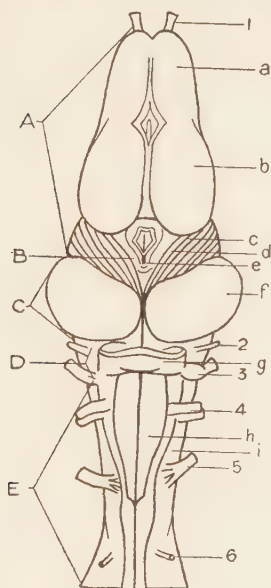


FIG. 62

Diagram of Frog Brain, Dorsal View. A, Forebrain; B, Tweenbrain; C, Midbrain; D, Hindbrain; E, Afterbrain. a, Olfactory Lobe; b, Cerebral Hemisphere; c, Optic Tract; d, Diencephalon; e, Pineal gland; f, Optic Lobes; g, Cerebellum; h, Fourth Ventricle; i, Medulla Oblongata. 1-6, Cranial Nerves (drawn from Jewel Models).

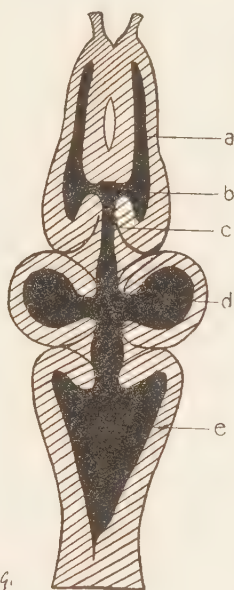


FIG. 63

Diagrammatic Horizontal Section of Frog Brain to show Ventricles. a, Olfactory Ventricle; b, Foramen of Monroe; c, Third Ventricle; d, Optic Ventricle and Aqueduct of Sylvius; e, Fourth Ventricle (after Ecker).

forebrain, also called the "cerebrum"—the largest and most conspicuous part of the brain—extends from the forehead to the back of the head, completely overhangs and covers the 'tween and mid-brains. Back of the cerebrum and meeting with it, is a much smaller rounded mass, the hindbrain or "cerebellum." The cerebellum, in turn, overhangs the afterbrain or "medulla oblongata." The medulla oblongata and the spinal cord are continuous.

The surfaces of both the cerebrum and cerebellum are convoluted; in the cerebrum the convolutions are irregular and deep; in the cerebellum they are less deep and regular and parallel. The surface of the medulla oblongata is smooth.

The weight of the adult human brain is about 48 ounces.

The spinal cord, like the brain, is not a solid structure. A small cavity called the "central canal" passes down through the center

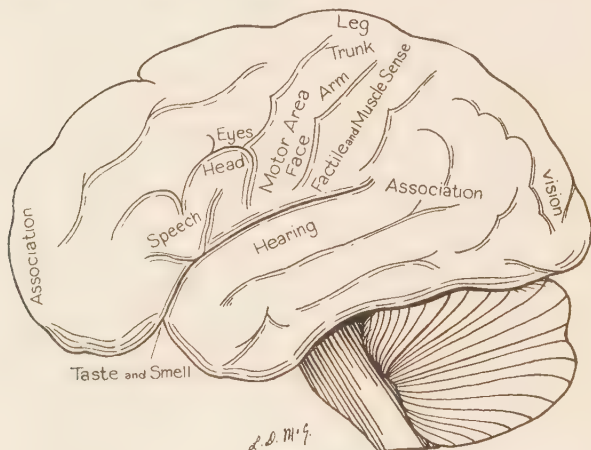


FIG. 64

Diagram of Human Brain showing Motor Centers in Cerebrum.

of the cord. This central canal opens into cavities or the "ventricles" of the brain (see Fig. 63).

A median longitudinal fissure divides the brain and spinal cord into right and left halves.

Both the brain and spinal cord are composed of a soft and jelly-like substance protected by three surrounding membranes called the "meninges." The brain is further protected by the brainbox in which it is inclosed while the spinal cord is protected by the spinal vertebrae surrounding it.

THE GRAY AND WHITE MATTER. In a section, an observer will note at once that the brain and spinal cord are made up of two different types of tissue: the *white* and the *gray* matter, the former composed of medullated nerve fibers, the latter of uncovered cell bodies and nerve fibers.

The gray matter occupies the longitudinal center of the spinal cord. A cross section gives one the impression of a butterfly surrounded by white matter (see Fig. 65). In the brain proper, however, the white matter forms the core and the gray matter surrounds it in a thick convoluted layer. In this gray layer, one finds groups of cell bodies, known as "nerve centers" in which are local-

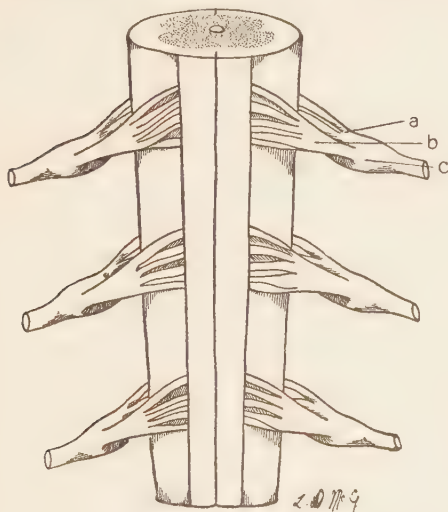


FIG. 65

Diagram of a Section of the Spinal Cord. a, Dorsal or Posterior Spinal Nerve Root; b, Ventral or Anterior Spinal Nerve Root; c, Spinal Ganglion.

ized the various body activities. Thus in the cerebrum one finds motor centers which govern the reactions of the trunk and limbs of the individual as well as his visual centers, auditory center, centers of taste and smell, and centers for speech, writing, etc., (see Fig. 64). In the cerebellum are located the centers for muscular coördination; and in the medulla oblongata the centers controlling respiration, heart action, and the contraction and expansion of the muscles in the walls of the blood vessels.

The discovery of these localized brain centers* is of immense value in brain surgery. In case of brain lesion or injury, the function interfered with often points the way to the part injured.

THE PERIPHERAL NERVOUS SYSTEM. Twelve pairs of cranial

*These localized centers of brain activity are not to be confused with the wholly artificial localizations of mental and moral attributes in the brain that form the peculiar feature of the pseudoscience of phrenology. Phrenology, under the name of cranioscopy, was first propounded by Gall, a Viennese physician, who claimed to be able to estimate the mental and moral powers of an individual by examining the contour of the skull. Gall argued that the more developed any mental or moral quality was, the larger would be that part of the brain representing it, and since the skull is but the brainbox fitting close to the brain, the contour of the container would reflect the contour of the contained.

The alleged science of phrenology was most unscientific because there is no evidence for the sharply defined localization of any mental or moral function in the sense that a definite brain area is the sole organ of a particular mental element, and, furthermore, there is abundant evidence against the notion that the outer surface of the skull indicates the degree of development of the brain within.

nerves arise from the more central parts of the brain in all vertebrates and extend in a series from the anterior part of the cerebrum to the posterior part of the medulla oblongata (see Fig. 62). These nerves distribute fibers to the eyes, ears, nose, tongue, heart, stomach, and larynx, as well as to certain muscles of the head. Some of the cranial nerves are purely sensory, such as the optic, the olfactory, and the auditory. Others are purely motor, such as the oculomotor which innervates certain muscles of the eyeball; while still others are mixed; i.e., they contain both sensory and motor fibers. The trifacial is an example of a mixed nerve. This nerve is sensory to the upper eyelid and side of the nose, and motor to the muscles of the jaw and to a part of the tongue.

From both sides of the whole length of the spinal cord 31 pairs of spinal nerves pass outward (see Fig. 65).

Each of these nerves passes outward from the spinal cord by two nerve roots, the anterior arising from the front or ventral side of the cord, and the posterior arising from the back or dorsal side. The posterior is the larger of the two roots and differs considerably from the anterior (see Fig. 65). The cell bodies of the neurons of the posterior root are contained in a small spherical mass of gray matter, called a "ganglion" (a group of nerve cells), which is situated within the nerve itself, a short distance from the point at which it branches off from the spinal cord and just before it joins with the anterior root to form a single mixed spinal nerve. The anterior root, on the other hand, has the cell bodies of its neurons lying within the gray matter of the cord itself. A second difference between posterior and anterior roots lies in the fact, that the posterior is composed exclusively of sensory or afferent nerve fibers and the anterior of motor or efferent nerve fibers.

At the point where anterior and posterior nerve roots fuse together to form a single mixed spinal nerve, the latter divides into two branches, called "anterior" and "posterior" branches and is composed of both motor and sensory fibers.

The anterior branch is the larger of the two. It makes a connection with the ganglia of the sympathetic system which supplies the organs of the body cavity. The remainder of the anterior branch supplies the neck, arms, legs, and walls of the chest and

abdomen. Frequently several neighboring anterior branches send out communicating branches to one another, each branch carrying fibers from one branch to the other, thus forming dense networks of nerves which are called "plexuses." There are five such plexuses, named from their position in the organism, the cervical (neck) plexus, the brachial (arm) plexus, the lumbar (loin) plexus, the sacral (lower loin) plexus, and the pudendal (pubic) plexus.

The posterior branch supplies the skin and muscles of the back.

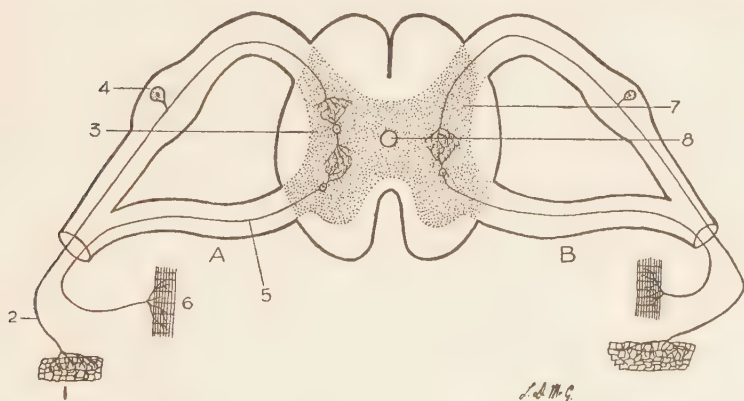


FIG. 66

Diagram of cross section of Spinal cord with Spinal nerves to show essential parts of a Reflex Circuit. A, Illustrating the parts necessary for the simplest type of Reflex Action. 1, Receptor; 2, Afferent Neuron; 3, Adjustor Neuron; 4, Dorsal Ganglion; 5, Efferent Neuron; 6, Effector; 7, Gray Matter; 8, Central Canal.

The nerve endings of both the cranial and spinal nerves lose their sheaths; i.e., myelin and neurilemma. It is these minute terminals of the cranial and spinal nerves which are especially designed to receive and to deliver impulses traveling to or from the brain and spinal cord. These highly specialized nerve endings are termed "end organs"; those of the incoming or afferent nerves are called "receptors," while those of the outgoing or efferent nerves are called "effectors." Receptors and effectors have already been mentioned in an earlier part of this chapter. Receptors for the most part are found in the skin, mucous membranes, joints, tendons and muscles; and are highly specialized dendritic processes of neurons whose cell bodies are located in the ganglia of

the brain on the posterior spinal nerve root. The effectors, on the other hand, are similarly specialized axon endings whose cells are located in the gray matter of the brain or spinal cord.

THE AUTOMATIC OR SYMPATHETIC NERVOUS SYSTEM. The automatic (self-ruled) or sympathetic nervous system presides over all those unconscious activities of the human economy, such as digestion, secretion, absorption, heartbeat, excretions, etc. Such activities go on continually whether we are sleeping or waking, and whether we are conscious of them or not. Some of such activities are partly conscious and partially under the influence of conscious will power such as breathing.

Along each side of the spinal cord, although lying in the outer surface outside the vertebrae and a little ventral, a chain of ganglia may be seen (see Fig. 66). This chain extends the entire length of the vertebral column. These ganglia (little spherical masses of cell bodies) are linked together by communicating branches with the neighboring spinal nerves, while in the region of the skull they are connected to the various cranial nerves. Numerous nerve trunks arise from the ganglia and the various uniting branches which form plexuses which in turn give rise to nerves running to the viscera. The chief plexuses of the sympathetic system are the cardiac or heart plexus; the solar plexus located behind the stomach and giving off branches to the stomach, intestines, liver, and kidneys; and the hypogastric plexus located in the lower portion of the abdomen.

The nerves of the sympathetic system differ from the cranial and spinal nerves in that they are gray in color and are non-medullated.

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CHAPTER XVII

ANIMAL PSYCHOLOGY*

In no branch of study is the student confronted with more difficulties in the way of separating fact from interpretation, and explanation from description, than in the field of animal psychology, and this, notwithstanding the fact that animal psychology owes its entire value to its ability to explain and not to describe.

The tendency of the human mind to read into an animal's actions the same motives and reasons that cause man to react in a similar manner is difficult to overcome. In fact, a definite word, *anthropomorphism*, is in common use among psychologists to describe just this tendency to humanize animals.

Still, the only way we have of interpreting the behavior of an animal must be in terms of human understanding, for we have neither language nor imagery which can bring to us the sensations, emotions, and driving force of an organism so totally unlike ourselves, as an insect, for example.

As one writer has said, anger with us is always associated with an increase in heartbeat and a more rapid breathing, and our nerves are all "set on edge," but an insect has a totally different set of bloodvessels, an entirely different breathing apparatus and a different nervous system. What are its accompanying sensations when it feels angry? In fact, a wasp often bites off its own abdomen when angry. How can we, when our respective organisms are so unlike, know much about how such animals feel?

Further, all of us have observed that probably most plays and novels hinge their plot entirely on some misunderstanding. If human beings, who have a common language to make themselves understood, are so frequently misunderstood, how much more will we not misunderstand and misread the actions of animals entirely unable to tell us anything in terms which are understandable to both?

*From Menge's *General and Professional Biology*, Vol. I.

It is for reasons of this kind that many throw up their hands in despair and insist that we never can know anything at all about the animal mind, but that if we wish to establish an animal psychology anyway, there is only one way to go about it, and that is, merely to study the behavior in the laboratory under set conditions so that we can learn just how each animal reacts to a given stimulus. Such a method assumes that all animals of the same sex, of the same age, and in the same state of health, will always react in exactly the same way when the same stimulus is applied under the same conditions.

The words "objective" and "subjective" are two of the most important terms used in psychology. The former is the term applied to all things which come under the senses. That is, a thing is objective when it can be observed and measured in the laboratory. It is anything, in other words, which occupies space. Subjective refers to those things which make no observable difference in space and which cannot, therefore, be measured in terms of the rule and scale of the laboratory. For example, changes in the mental world, such as thought and feeling, are subjective. In the classic sense, *subjective* means the act of the mind itself or what is in the mind, while *objective* refers to the matter with which the mind works.

An illustration of these two terms, as commonly used, comes to mind. Suppose a neurologist were to examine the optic nerve and the optic centers of the brain of a student while the latter is reading a letter. The neurologist could probably tell that the optic nerve and center were functioning, but he could never tell what the letter contained, nor could he see what emotions were called forth in the mind of the student. The movement in the nerve and nerve center would be objective, while the emotional impression made on the student would be subjective.

Not only would the neurologist be unable to observe the emotional impression made upon the student, but he would be unable to tell why certain vibrations which, so far as observation goes, are all alike, should produce sensations of red or green in one case, and another color in another case.

All our emotions, longings, ambitions, thoughts, and ideas, so

long as they remain mental states, are subjective, while when they express themselves as acts, they become objective.

WHAT IS PSYCHOLOGY?

Psychology is the study of the subjective world. The word "psychology" actually means the study of the *soul*, but since laboratory methods have come into existence in psychology, and laboratory men think only in terms of measurable substances, it is commonly said to be the study of *mental phenomena*.

Since the laboratory methods of studying everything objectively under set conditions have made their way into psychology, the workers in this field have become divided into various camps or schools. First, come the Behaviorists, who insist that the *results* of mental activity are *actions and reactions to given stimuli*, and it is only these results which can be measured and which, therefore, may validly be used as data on which to form any theories of the mental life of animals. Second, come the Introspectionists, who follow the classic method of antiquity. They insist that the only real way of studying mental life is *to introspect*—to look into our own mental life and try to understand how and why we do what we do under varying conditions. They insist that we must analyze our own thoughts, motives, and emotions, and then, if an animal has an organization quite like our own, we may validly assume that it, too, functions somewhat like our own.

Since extremists on any side of a discussion are likely to go astray, it is always best not to follow entirely any single group to the exclusion of another. To be fair, one must use anything and everything that will throw light on the problem one is trying to solve.

The word *mind* is another confusing term. By the older writers it was used to designate *personality* of an individual. That is, if one says with Descartes, "I think" therefore "I exist," and "I" which does the thinking and which does exist is the true personality, the true mind. Or, one may note that it is quite common to dream that one has died and attends one's own funeral. That which can look at its own physical body as the physical copartner of the true ego—of the individual's personality—is the *mind*, or as the older writers called it—the *soul*.

Not only do we here see a distinction of the ego, or personality proper, as *mind*, but we also note that the mind is separate from the thoughts which the mind brings forth. We can, therefore, understand these writers when they tell us that the brain is in turn the organ of the mind, but not the mind itself.

The average laboratory man will have little of this, however. He insists that mind does not exist as distinct from thought and emotion. He means by mind the whole "stream of consciousness" of the individual—all thoughts such as one has ever had, plus all one's emotions, such as pleasures and pains—accumulated experiences of the individual, in other words.

The laboratory men do, however, admit two divisions of this mental life, namely, *consciousness* (awareness) and *feelings* (emotions or affections, such as pleasure and pain).

The reader can understand these two divisions easily if he will think of breaking a bone in his body. It is one thing *to know* (be conscious of) that the bone is broken, and another thing entirely *to feel* the pain it may cause.

MIND AND MATTER

The idea of a difference between the mind and the physical body containing it, leads us to note the distinction between mind and matter. Those who accept this distinction are called "dualists."

Great conflicts have been waged by the learned of all times as to which is the more important of the two—mind or matter—and which was first upon the scene of existence. Some have contended that mind (spirit) came first, and this, then, was the cause of the physical universe (matter). Such contenders are known in philosophy as "spiritualists." Others contended that matter was first on the scene, and that mind was late in its arrival, because it is only an emanation of some kind from the physical. That is, mind is something like the secretions from ductless glands which we know little about, but which we do know exist. Such men are called "materialists." Yet another group insisted that as mind and matter are always together, neither may be given the preference. Both are different sides of the same coin. Each thought wave is always associated with a nerve wave of some kind, and neither can exist without the other. Such men are called "monists." It

will be seen that the term "monists" is applied to this group because they do not accept a dualism in life.

These different groups of contenders attack psychological problems with different prepossessions. The spiritualist is likely to call himself an *interactionist* in psychology, the materialist a *behaviorist*, and the monist a *parallelist*.

As it makes a profound difference to a patient which one of these theories his physician holds, the reader must know what each term means, or he will be unable to pass judgment on the many and conflicting discussions which are ever coming before him.

The interactionist holds that the state of mind of an individual can and does influence his physical being and vice versa. An example of this is a man worrying over financial losses, whose body becomes run down until disease clutches him.

The behaviorist insists that only a definite physical reaction, measurable in the laboratory, is valid data on which to base a scientific conclusion, and that until the individual mentioned above shows a definite measurable reaction, there is no change which we as scientists can use or accept.

The parallelist, insisting as he does that both the mentality and the physical organ which is associated with it, are different sides of the same thing, must necessarily consistently claim that the mind is totally unable to influence the body and the body totally unable to influence the mind. In fact, one prominent parallelist says that one may as well expect a piece of beefsteak put into a sausage machine to come out a moonlight sonata as to expect either body or mind to influence each other.

It is, therefore, only the interactionist who can consistently speak of nervous and mental diseases, and who can consistently use both physical and psychic remedies.

STRUCTURAL AND FUNCTIONAL PSYCHOLOGY

At this point we may consider what is commonly designated as structural and functional psychology.

Structural psychology concerns itself with (1) the general organization of an organism, (2) the general organization of its nervous system, and (3) the organization of the specialized nerve parts, such as the eye, ear, nose, etc.

Functional psychology is interested in (1) the general way an organism reacts (discrimination), (2) whether the organism can modify its action (docility), and (3) in how many ways and in what way its behavior will vary (initiative).

Again the reader must be cautioned not to let one side of a problem cause him to discard much that is of value in opposing schools of thought. Just as those who are primarily interested in nothing but anatomy, are likely to leave out important functional causes in a disease, so those primarily interested in physiology are likely to forget the structural elements which may contribute points of tremendous importance.

All schools of science have been drilling into the student the supposed "fact" that "structure determines function," but since the very recent work of Carey, who converted unstriated bladder muscle of a living dog into living heart muscle by simulating heart conditions in the bladder, we must insist that function has just as important a part in changing and determining structure as structure has in determining function. However, we must not forget that even in the case just mentioned, the substance to be changed was already present and must have possessed the potentiality of change before it could be worked upon.

METHODS OF COMPARATIVE PSYCHOLOGY

With this introduction we can better understand the two ways in which the study of comparative psychology is approached by the modern laboratory worker. First, we may take a highly developed individual, such as man, and after analyzing his mental world, apply the knowledge thus gained to the lower forms. Second, we may follow up, step by step, the increasing learning ability on the part of all phyla of animals, beginning with the unicellular and passing upward through an ever-increasing scale of ability.

It is this second method which seems to have found most favor with animal psychologists.

In reading works on animal psychology, one is always confronted with a great confusion of terms. In fact, one finds here the same difficulties that confront the student in any of the biological sciences. The first workers in all these fields were philosophers,

and were interested primarily, and sometimes only, in the human family. The terms, therefore, which these men used, although worked out with great precision, applied only to man.

The newer writers took many of the older labels and placed them on new bottles, so to speak. This has caused a world of confusion, not only to new students, but to many well versed in language and literature.

Such words as mind, intelligence, reason, memory, consciousness, sensory or associative memory, instincts, and reflex actions, are some of the terms which the reader must use, and which have many conflicting meanings in modern literature. It is imperative that the reader obtain a clear and concise definition of these terms and use them only in this restricted sense. Then only can he understand the meaning which different writers assign these words, and then only can he know whether they are calling other things by the same name, or giving different names to the same thing.

INSTINCTS AND REFLEX ACTION

We shall have to speak of instincts immediately, so it is well to begin with this term. *Instincts* are defined as *inherited tendencies in an organism which cause protective reactions when harmful stimuli are applied*. For example, a frog, even after both cerebral hemispheres are removed, will still scratch the part of its body to which a drop of acid is applied, and it will even snap at and swallow a fly which has been placed on the tip of its nose. Again, a fly will walk, fly, and clean its legs and wings, after its head is entirely removed, and the writer has kept a decapitated cat alive for many hours by artificial respiration and caused it to perform many instinctive actions such as scratching itself, waving its tail, etc.

In order to understand reflex action, it is first necessary to know the meaning of a nerve arc (Fig. 66). This latter is merely the entire nerve path over which an impulse passes to a nerve center and out again to a muscle cell. It must, therefore, consist of the nerve ending of a sensory nerve (receptor) through which the impulse is received, and the sensory nerve fiber which carries the impulse to the nerve center to join at this point with a motor nerve fiber which in turn carries the motor impulse to the *motor-nerve ending* (effector). This motor-nerve ending is always located

in some muscle fiber. Psychology textbooks often speak of a nerve arc, as "a perception with a motor impulse."

A *simple reflex action* is one that passes over such a simple nerve arc without first passing to the higher nerve centers, or, we may say, one which does not come into the *consciousness* of the individual in whom the action takes place. Such a reflex action is, therefore, purely physical. There is no need of assuming any mental state or sensation as an accompaniment.

When an individual is born, his nerve arcs are set in some form or another, so that with one individual the same stimulus will cause quite a different reaction, than it will in another. But, just because these nerve arcs are *set* in the way they are, the same nerve arc will always react in the same way to the same stimulus, if all other conditions are equal. For example, a child may have grown accustomed to saying "I is" for "I am" and have said it so often that it finds it very difficult to correct itself. Now, if we constantly force the child to use the form "I am," the particular nerve arc which carried the "I am" reaction will become relatively stronger than the one which carried the reaction "I is," and then, and not until then, does the latter phrase become a sort of second nature to the child.

So, too, a puppy that has the vicious habit of snapping at passers-by, can be made to react differently by giving him a whipping several times, immediately after he does the undesirable act.

In both these cases memory enters, but only a simple sensory memory (association memory) which has little to do with any thought. The impulse (inner stimulus) in the puppy to snap, is great, and so the "snapping nerve arc" carries the impulse and the snapping is done; but the punishment, which has been meted out, has set up an impulse of an opposing nature, and as soon as this latter becomes the stronger impulse, the puppy has been trained.

We may say in this case that the puppy has the desire to snap, and the nerve arc, which carries this snapping impulse, begins to function. But the whipping has caused a new nerve arc to function at the same moment, so that a third nerve arc, that of inhibition, comes into play and the animal does nothing. This is quite similar to the reaction of persons in hypnosis. Here an individual is told he cannot bend his arm. The impulse not to bend the arm

is just as strong as the one to bend it, so no movement takes place.

An impulse is defined as an *inner stimulus*.

It is well to bear in mind the facts related in the foregoing paragraphs as these show the possibility of two opposing impulses and even two opposing reactions taking place at one and the same time over different nerve arcs. Often we read of lower organisms possessing discriminating powers of various kinds which can be interpreted in quite different ways from what the writer of such an account would have us believe. We need only remember that there can easily be one set of nerve arcs functioning for the acceptance of food and another set for the rejection of it, so that it depends on which set carries the stronger impulse as to whether the animal accepts or rejects the food. It is by no means necessary to assume any discriminating ability.

There are also *complex reflex actions* making use of several nerve arcs, sometimes often forming regular chains of reactions. In these cases, the result of one stimulus sets up another, and so on. In fact, we call such continued setting up of stimuli "reflex chains." As an example, we may refer back to the frog whose cerebral hemispheres have been removed. If we place a fly on the tip of its nose, that stimulus sets the "snapping" nerve arc functioning. Then as the fly is taken into the mouth, a new nerve arc causes a swallowing impulse, which sets up reactions of still other nerve arcs which in turn cause the digestive glands to pour out digestive substances.

It will be noted that such reflexes are quite useful to the animal, and it will be remembered that our definition of instinct called attention to the *protective* value of inherited nerve arc actions.

Instincts may be *deferred*, that is, they may not be observable at birth, but come forth only later in life when various glands begin to pour out secretions which affect many parts of the body. It is often stated that instincts are the "inherited habits" of the individual's ancestors. This was Lamarck's idea. But this cannot be, because many animals lay their eggs before they themselves have developed the later characters which the offspring possess. Consequently, the young would have to inherit a habit that the parent was going to form later. This is somewhat like saying that because a mother is divorced, her daughter inherits a desire for

divorce from her mother, which, therefore, resulted in the daughter also obtaining a divorce.

While instincts are made up of reflexes, the reflex proper is said to affect only one part of the organism, while instinct affects the entire body. That is, we should say the winking of the eye, when danger threatens, is *reflex*, while running away from the danger is *instinctive*.

Instincts really consist of inner driving forces which make the animal possessing them restless until the instinctive act is performed. However, we must remember here also that just as with the impulses already mentioned, there may be conflicting instincts. In such cases the stronger will come forth. Or both may be equally strong, so that no action at all will take place.

TROPISMS

Recent psychology often speaks of *tropisms*.* A tropism is a movement of some kind on the part of a living organism. Those who wish to interpret all action of living organisms in terms of physics and chemistry are fond of using this term. Such men prefer to cast the term "instinct" to the four winds and explain everything in physicochemical terms. They insist that a caterpillar climbs to the end of a twig on account of the chemical change in its body that is caused by hunger, let us say. New chemical molecules and adjustments are forming, and this makes one part of the body lighter than another, so that the laws of physics enter and the heavier part will be followed by the lighter in going downward, or a chemical affinity of some nature will draw the chemical substance of the animal toward it. After having eaten the tiny bud on the twig, a new chemical change takes place and so the animal must, whether it will or not, obey the next chemical and physical change and descend from the twig. In this connection Dr. Vernon Kellogg recently called attention to a scientific friend who explained to Dr. Kellogg that the reason he took a corner seat in a restaurant was a primeval impulse which made him want to have his body in close contact with the wall. But, as Dr. Kellogg said, the reason he chose that particular

**Tropisms* really mean growth reactions and *taxis* mean movement, but most writers use *tropism* to include *taxis*.

seat was because he had made an appointment to meet a friend there.

ANIMAL LEARNING

As the principal test of an animal's mental ability is the rapidity with which it learns, we must know what learning means. *Learning* means the ability on the part of a living organism to vary its actions according to some definite plan which will show that it has profited by past experience.

In this connection one is also confronted with difficulties as in other fields. Suppose one is attempting to see whether an animal can distinguish between colors and then learn to go toward one hue rather than another. Suppose now, that the animal does not show any more inclination of going toward one color than toward another. This by no means proves that the animal cannot distinguish, or is unable to learn, that there are two colors. It may mean nothing more than that colors make so little difference to the animal that there is no reason (motive) for his choosing one rather than the other. In such an instance the animal's reaction to both colors would be identical, and one could prove little or nothing from its behavior.

Another animal may be thought unable to learn because it tries a problem a few times and then ceases to react at all to the stimulus. This may be due entirely to fatigue of the organs used, and not to inability to learn. That is, the nerve receptors may become dulled or tired by new stimuli which are foreign to the animal in its native career.

Or again, some sensation may be pleasant to an animal only if secondary factors are present, such as the taking of food only when it is hungry or when the body is in good health. But surely the rejection of food does not mean that the animal can or cannot discriminate between foods. We often will not eat one kind of food, while another is relished, or we often will just as readily eat ice cream, candy, or fruit, and show just as much desire for the one as for the other; but this certainly does not mean that we do not know the difference between these three types of edibles.

Then, too, the state of health makes a tremendous difference in what an animal will choose. Dogs and cats eat certain plants at certain times, but at other times they will not touch these foods.

But do they not know the difference between these plants and other food?

HABITS

Then, too, an animal may be trained to do certain things. But suppose it does these things without having been trained. Can one not argue as well that the animal merely stumbled upon doing the act, and then doing it often, the nerve arcs became *fixed* and the animal can no longer help itself? It is now a *habit*.

Habits are but acts performed by fixed nerve arcs.

The question may arise as to what difference there would be between psychology and physiology if all we are to study consists of nerves and reactions. Really, there would be no difference in *content* of the two sciences, the difference would consist in *emphasis*. The psychologist lays stress on emotions, feelings, etc., and the physiologist on the simple observable reaction which follows a given stimulus. The psychologist, in other words, wants to know how the animal feels and what it has in its consciousness when a stimulus is applied and its actions are changed.

The unicellular *Paramoecium* has only two simple reactions, namely, backward and forward movements, while the vertebrate frog can move in many and varying ways in order to get out of harm's way. Probably all animals can learn. That is, they can be taught to make some change in their behavior, but the rate of speed with which they can learn probably becomes greater as we ascend from lower to higher phyla. The same may be said of the complexity of the problems to be learned.

When left to themselves, all animals and children learn whatever they do learn by what is called the trial-and-error method. This simply means that they try something and, if this something is unpleasant or painful, they try something else. Contrariwise, if a reaction produces pleasure, it is done again and again until it becomes a habit.

All learning, no matter what it may be, must be based on instinct in its widest sense. That is, the problem presented must be something which can be solved by making use of some instinctive behavior of the animal upon which we wish to experiment. For example, a cat can be placed in a closed box in which there is a lever which when pressed will open a door. Now, cats are excit-

able and when excited will begin to leap about. This is an instinctive action. If, while leaping about, the animal strikes the lever and the door opens, it can be trained, by inclosing it often enough in the same or a similar box, to press the lever without going through the leaping first.

AWARENESS IN ANIMAL LEARNING

Learning, then, really means *profiting by past experience*. But no profiting by past experience is possible unless such past experience is remembered. Now, such memory by no means must be a definite thinking out of a past event and then sitting back and saying "I will" or "I will not do this again." Most physical experiences, even in man, are merely nonconscious functioning of nerve arcs. Neither men nor the lower animals do any thinking in regard to these simple or complex chain reflex actions. It is a mere association of one stimulus starting another and is called, as already stated, "sensory" or "associative memory."

There may, or may not, be an awareness of doing an act, plus an associated pleasure or pain sensation. That is, there may be consciousness not only of the fact that an act is being performed, but there may also be an awareness of pleasure and pain accompanying it, though there is little proof that a definite thought—that is, reasoning—is performed, and that it is then due to such reasoning that changes of action are made. These learning acts are in all probability due only to sensory memory.

An example comes to mind. We have all heard someone tell of a horse that knows when Sunday comes, that being the only day when the animal does not come out of the stable to be harnessed as soon as its master appears.

But does this show that the horse can count up to seven and has a sort of mental calendar on which he checks off the days? By no means! All it may mean is that, if a horse works six days in the week, there is a certain feeling of tiredness which has become associated with that amount of work, just as a blind man can tell by his "feeling" how many blocks he walked and when it is time to turn without counting the blocks.

We may then conclude that all animals may be conscious to some extent; that is, they may be aware of their actions, although

this has nothing to do with reasoning—with thinking.

The veteran experimental psychologist, Professor William Wundt, said, "Animals never think and humans but seldom." Most animal psychologists hold to this dictum, if by "reason" is meant true thinking, that is, a weighing of two or more sides of a problem and then by a definite mental act coming to a decision or conclusion as to what is to be done. In other words, thinking means to use *abstract ideas* and to *form conclusions*.

There are many writers who mean by the term "thinking" only an ability to profit by past experience. Others likewise speak of "intelligence," which should mean only the ability to think, as any associative memory. This is really placing old labels on new bottles and is very confusing to the man who wishes to know both the past and the present of a branch of science.

HUMAN VS. ANIMAL INTELLIGENCE

The desires of the different men in animal psychology must be taken into consideration when reading their respective works. There are those who wish to show that there is no real difference between man and the lower animals. These insist that man has nothing distinct from the lower animals except an articulate language, but that man's seeming difference in the mental world is only a little greater development of animal characteristics. Language, they often say, is the cause of man's greater mental ability in that he can by this means write down his findings so that others may profit by them.

Those who hold that man is something separate and distinct from the animal, call attention to the fact that language but expresses thought, and one must have thought before he can develop a language, rather than language being the cause of thought. These men also insist that there is no proof that any animal has ever "reasoned" out a problem in the way mentioned in an earlier paragraph, and therefore no animal lower than man can be said to have any "intelligence" in the classic sense.

These latter men would say that hundreds of thousands of cats, dogs, and even apes (which are considered the more intelligent animals) are very fond of warm places. Such animals have lain before hundreds of thousands of open fires and enjoyed the

warmth. They have seen their masters keep the fire aglow by placing fuel upon it, and yet not in a single instance has any animal drawn the very simple conclusion that it is the fuel which keeps the fire going, and has, therefore, placed (without being taught), a single stick of wood on the dying embers.

Not only this, but the child, when it grows up, teaches others, and our schools and colleges are all arranged for the sole purpose of making a young man and woman at an early age know what it would take a very old person centuries to learn by personal experience. No animal is known to teach another a trick which it itself has learned from a third individual, unless, of course, the act is instinctive and would have been learned anyway.

Whether one thinks of man as but a more highly developed lower animal, or whether one looks at man as a being apart, all agree that man can reason, whether he often does or not. All agree that man has larger brain hemispheres of finer texture than organisms on a lower scale; that he has an upright posture and a more delicate hand; that he can use tools, and has the foresight to be able to raise his own food and to live in cold climes by understanding the use of fire; and above all, that he is set apart from other creatures not only in having an articulate language, but also in having a knowledge of what he should and should not do—in other words, that he has a moral sense.

So, too, all are agreed that the trial-and-error method of learning shows infantile, or animal, intelligence and not human intelligence. All education, all colleges and universities have been brought into existence to present principles; that is, to present a mental and cultural gauge, so that each individual need not try out every detail of experience for himself; but, that he can, by learning the principles and laws which govern nature, sit back and "figure out" or "reason out" whether a given conclusion can or cannot be true.

This comparison is just as workable in the political and religious world as it is in the scientific. Here is shown the difference between the educated and the uneducated man. One must not feel hurt or surprised if an educated man, knowing his principles and his laws, laughs at one who proposes a problem or a solution of a problem which can immediately be seen to be erroneous. The un-

educated man cannot understand or see this until it has been tried and found unworkable.

From what has been said we must, if we wish to be sure that we are right, know what a writer means by his terms; we must be sure that we are not reading too much of our own thoughts into an animal's acts; we must be sure that we are consistent in our interpretations and that, if we explain an animal's behavior in terms of tropisms, we must also interpret man's in much the same way; we must insist that the observer who is attempting to convince us that his theories are correct, has a scientific training and can justly weigh all matters that make a distinguishing difference in our interpretations. That is, he must be able to separate fact from inference. We must insist that he be intimately acquainted with the habits of the animal he is discussing, so that he will not assume, for example, that an animal, like many insects, which have an instinctive impulse to cover up obstructions, is showing great intelligence when it covers up a minute stream and thus forms a bridge and crosses it. We must insist that he know the past experience of the particular animal he is discussing so that he will not confuse an associative memory with true intelligence. We must insist that he has no personal affection for the animal and thus wants to make it "show up" well. And lastly, we must insist that he do not let his desire to tell a good story gloss over important details and leave out others.

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